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TECHNICAL REPORT
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# A STUDY OF FORCES CAUSED BY HEAD IMPACT ON AIRCREW PERSONNEL ARMOR UNDER SIMULATED CRASH CONDITIONS

by

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Natick, Massachusetts 01760

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## FOREWORD

This report describes the methods and results of an experimental program to determine the force-time relationship resulting from head-neck interaction with three types of aircrew armor, with and without aircrewman helmets.

This report was prepared by Dynamic Science, a Division of Marshall Industries, Phoenix, Arizona. The program was accomplished under Contract No. DAAG17-67-C-0138 for the U. S. Army Natick Laboratories, Natick, Massachusetts with Edward R. Barron serving as Project Officer and Stanley D. Tanenholtz as Technical Consultant.

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# ABSTRACT

The results of a test program conducted to determine the magnitude, duration and shape of the force - time relationship resulting from head impact on personnel armor in a crash situation are presented.

The program was divided into two major tasks. The first included modification of an armor front torso plate to carry the test instrumentation, modification of the anthropomorphic dummy to improve human simulation, and modification of the UH-1B/D armored crew seat to prevent failure. The second task involved the performance of 12 dynamic tests using two different types of aircrew personnel armor, both with and without a protective helmet.

The test results indicated that significant head/armor impact occurs most frequently in the chin area (7 times in 12 tests). Such contact produced impact pulses that were triangular in shape with peak loads ranging from 27 to 500 pounds, and time duration ranging from 0.025 to 0.045 seconds. Loads on the chin of this magnitude and duration would not be expected to produce serious injury to a human.

Specific modifications to the armor are recommended to further reduce the injury potential.

No major seat failures occurred during the test series.

# A STUDY OF FORCES CAUSED BY HEAD IMPACT ON AIRCREW PERSONNEL ARMOR UNDER SIMULATED CRASH CONDITIONS

## 1. Introduction

In April 1968, the U. S. Army Natick Laboratories published the results[1] of a series of dynamic tests conducted to determine the possible physiological effects of personnel armor on aircrew members involved in a crash situation. The results of these tests indicated that, while the dangerous effects of the aircrew armor during a severe crash are relatively few, a potential exists for severe neck and face injuries due to contact with the upper edge of the chest armor. Further study was recommended to obtain more definitive data on these contacts, and to include the determination of the magnitude, duration and pulse shape of the contact load. This report presents the results of that study.

## 2. Analysis of the Problem

### a. General

The head of an aircrewman in a crash situation is subject to contact with his personnel armor in two major areas, as shown in Figure 1. These are defined arbitrarily as the face, which extends between 1 and 2 in Figure 1, and the neck, which extends between 2 and 3. Violent contact of the face with the armor could produce injuries such as fractures of the skull or facial bones, brain damage, lacerations, bruises and loss of teeth. It is more likely, however, that such impact would render the victim unconscious with only minor injuries initially but leaving him vulnerable to subsequent serious or fatal injuries due to postcrash fire, drowning or hostile action.

Contact of the neck with the armor could produce serious damage, even if such contact is not particularly violent. The most dangerous possibility is a fracture of the trachea, especially at the larynx. Such a fracture could easily result in death by asphyxiation due to a vocal cord spasm or collapse of the trachea.

Because of the difference in vulnerability of the two areas in question, this study can be divided into two major areas of interest:

(1) Determination of the magnitude, duration and pulse shape of the head/armor contact loads.

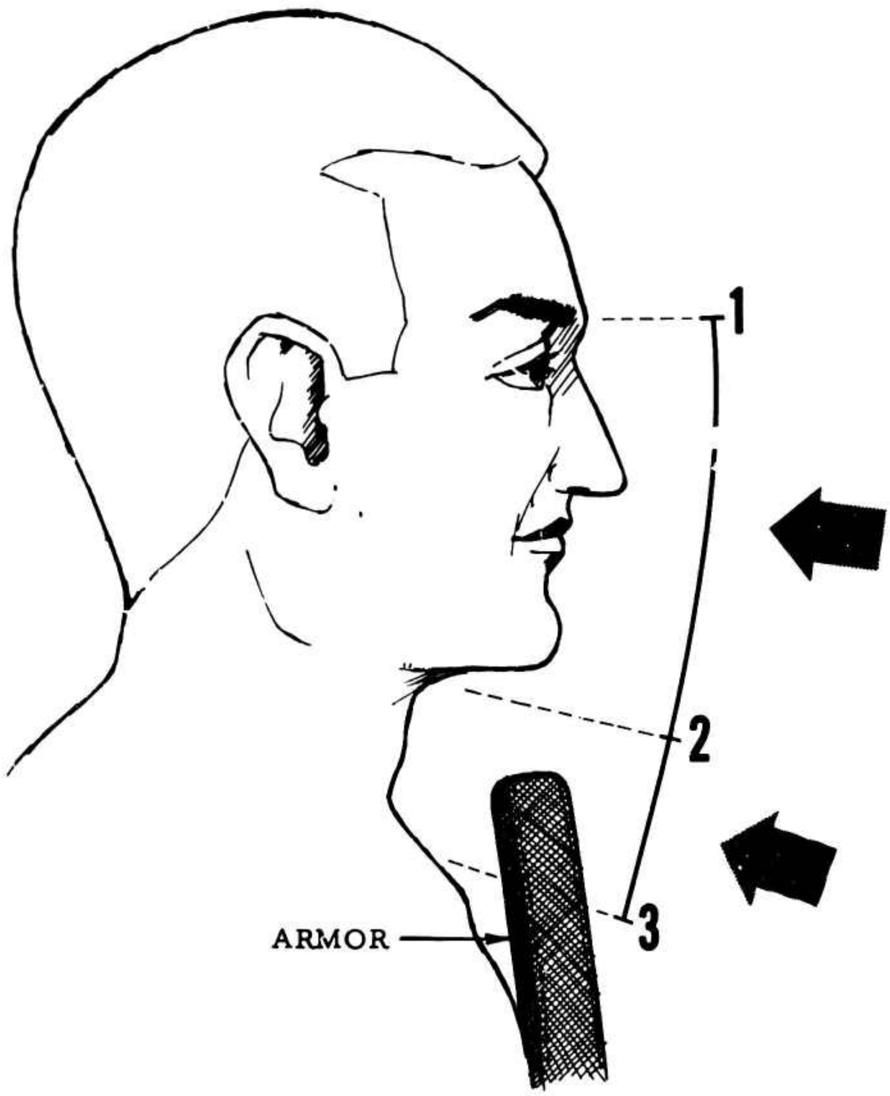



Figure 1. Face/Armor Contact Zones.

(2) Location of the point of contact.

b. Simulation of Human Face and Neck

Simulation of the human face and neck was provided by an anthropomorphic dummy. To improve the simulation, two modifications of the dummy's neck were required. The first of these modifications consisted of removing the steel ring installed on the dummy to join the head and neck "skin". The neck area was also padded with foam rubber to closely simulate the human neck. The second modification involved replacement of the existing neck vertebra assembly with an assembly having more of the characteristics of the human neck.

The dummy's face required no modification, since its conformation was an acceptable simulation of the human.

c. Elimination of Seat Failures

Since it was desired to test under conditions as close as possible to those under which the armor is used, UH-1B/D armored seats were chosen for the tests. Previous experience[1] with these seats has shown that they are prone to failures of the slides and rear columns. The seats were modified to eliminate these sources of failures.

d. Impact Conditions

The impact conditions chosen for these tests were intended to maximize the frequency and severity of head-armor contacts without exceeding either the limits of human tolerance or the physical limits of the seats.

3. Plan of Approach

a. General

The objective of this program was to conduct the necessary dynamic tests to quantitatively determine the magnitude, duration and pulse shape of the force-time relationship resulting from head and/or neck contact with the aircrew personnel armor and to evaluate the injury-producing potential of such contacts. In addition, the effect of wearing the aircrewman protective helmet with both the standard aircrew protective armor and the new combination flak/small arms protective vest was investigated to test the hypothesis that the added weight of the helmet would increase the contact load between the head/neck and the armor.

To accomplish this objective, the program was divided into two major tasks as follows:

(1) Modification of armor panel, anthropomorphic dummy and UH-1B/D seats.

(2) Dynamic testing.

b. Modification of Test Items

(1) Armor Modification

To record the data required by the program objective, a piezoelectric load cell was installed flush with the top edge of a chest armor plate. A portion of the armor was cut away in this area and the load cell, mounted on a steel bracket, was attached to the armor using Epon 901/B-1 adhesive. Figure 2 shows the completed installation. Additional data on the load cell are found in Appendix B, Instrumentation. This modified armor plate was used in both the standard aircrew protective armor and the new combination flak/small arms protective vest.

Figure 2. Front Armor Plate with Load Cell Installed.

(2) Anthropomorphic Dummy Modifications

To improve the human simulation characteristics of the anthropomorphic dummy, several modifications were made. The first modification was to improve the neck vertebra assembly. The original neck vertebra assembly consisted of a series of steel vertebra strung on a steel cable as shown in Figure 3. With this arrangement, the only way to adjust the resistance of the neck to motion was to adjust the tension on the cable. Such adjustment also varied the maximum rotation of the head. The replacement assembly consisted of a series of individually adjustable ball and socket joints separated by compressible rubber washers. Figure 4 shows this new neck assembly installed on the dummy. Adjustment of resistance in each joint is accomplished by adjusting large Allen screws projecting from the rear of each joint. Tightening these screws forces a friction pad against the ball of each joint, producing simulated muscle resistance without limiting head rotation.

The configuration of the dummy neck was also found to require modification. In its original form, the neck consisted of a thick rubber skin covering the vertebra assembly. A steel collar was used to join this neck skin to the body skin. Obviously, this combination of steel collar and rubber skin would present a poor simulation of the dynamic response of the human neck in the event of neck/armor impact during the tests. Since no definitive data were available concerning the force-displacement characterisitics of the human neck, it was not possible to design an exact simulation. The simulation was improved by removing the steel collar and installing foam rubber padding over the vertebra assembly as shown in Figure 5.

The modified dummy wearing the instrumented armor is shown in Figure 6.

In addition to the modifications just discussed, the dummy had previously been fitted with an instrumented vertebra (Figure 7) to measure vertebral loads under dynamic conditions.

(3) Seat Modifications

The four UH-1B/D armored crew seats used in these tests required several modifications to enable them to withstand the test loads without major failure.

The original rear columns of steel tubing having a wall

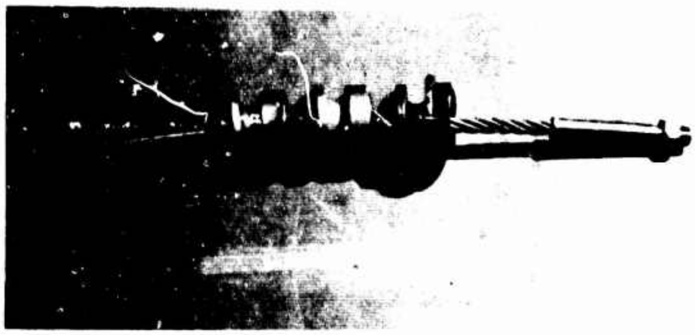


Figure 3. Original Neck Vertebra Assembly.

Figure 4. Replacement Neck Vertebra Assembly.

Figure 5. Foam Rubber Padding Installed on Neck of Anthropomorphic Dummy.

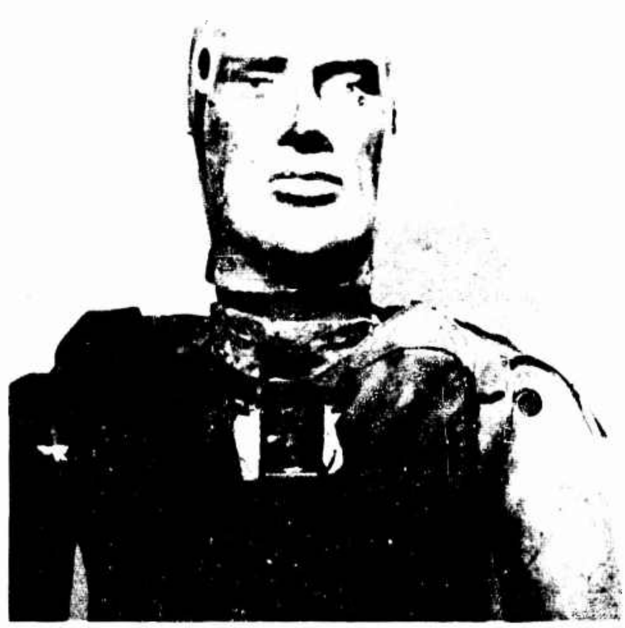


Figure 6. Modified Anthropomorphic Dummy Wearing Instrumented Chest Armor.

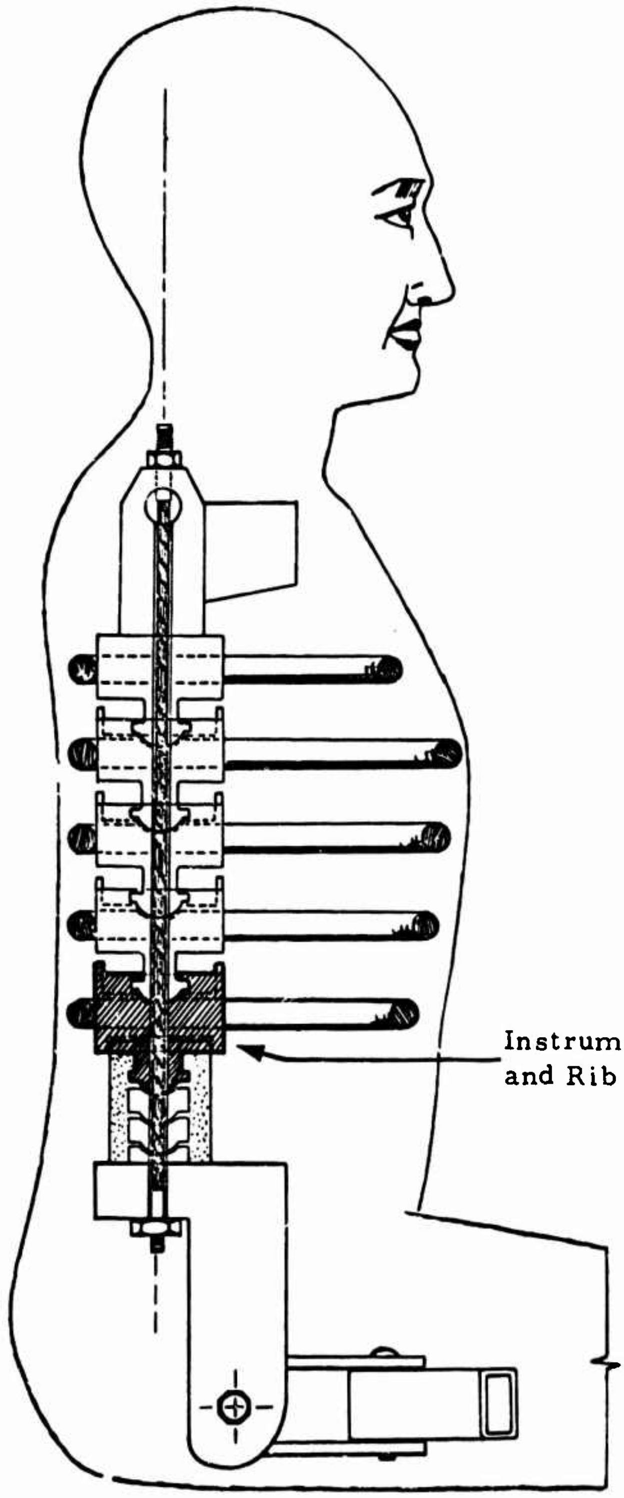



Figure 7. Location of Instrumented Vertebra.

thickness of 0.060 inches were replaced with columns of 4130 steel tubing having a wall thickness of 0.180 inches. Figure 8 shows these columns installed on one of the seats.

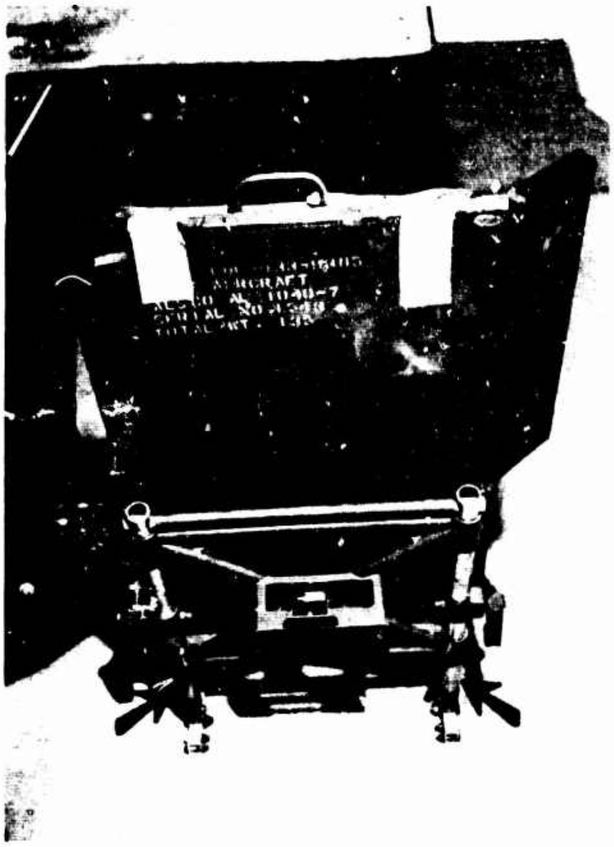


Figure 8. UH-1B/D Armored Crew Seat.
(Arrows indicate modified rear columns.)

New seat slides, incorporating several changes from the original slides, were also fabricated for these seats. The new slides were 2-1/2 inches longer to provide additional support to the front of the seat. An extra adjustment roller was also installed at the front of the slide to further improve support in this area. Finally, extra brackets were installed to attach the inboard front side of the slide to the front cross tube. These brackets provided for symmetrical loading of the slide at this point to prevent a twisting failure of the slide. Figure 9 shows the modified slides installed on one of the seats. Figure 10 shows a side view of the modified seat.

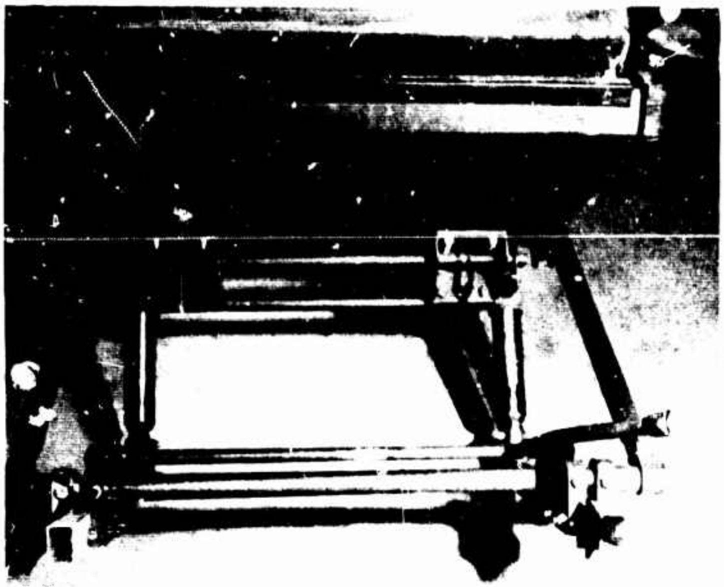


Figure 9. Front View of Modified UH-1B/D Seat. (Note (1) extra length of slide, (2) added inboard slide mounting brackets, and (3) additional support roller visible inside slide.)

During the dynamic tests, the front cross tube, made of thick-walled chrome-alloy steel, was found to be subject to bending failure and was replaced by a solid bar of 4130 steel (Figure 10).

c. Dynamic Test Series

A series of 12 dynamic tests were performed on the horizontal accelerator utilizing the 2 types of personnel armor provided, both with and without the protective flying helmet (FSN 8415-935-6335). These tests are reported in detail in Appendix A.

4. Evaluation of Test Results

a. General

The results of the 12 dynamic tests indicate that the peak loads generated during head/armor contact may vary widely, according to the type of armor used and whether or not a helmet is worn. The pulse shape, however, is consistently triangular with a total duration of 0.025 to 0.040 second.

Figure 10. Side View of Modified UH-1B/D Seat. (Arrow indicates front cross member made of solid steel 4130 bar stock that replaced the original steel cross tube.)

Examination of both the posttest photographs and the high-speed film showed that when head/armor contact occurred, the point of contact was on the point of the chin. No contacts with the throat area were observed.

The fact that significant head/armor impact occurred in only one instance during Tests 1 through 4 and that this contact produced a peak load of only 27 pounds would suggest that the loads measured in previous similar tests[1] were excessively high. The method of measurement used in the previous tests could account for this difference since in those tests the impact occurred on a styrofoam block positioned approximately one inch above the top of the armor. This gave the effect of having the armor one inch nearer the chin, resulting in head/armor contact earlier in the impact sequence before the restraining action of the neck had time to take effect.

The wearing of a helmet with the standard aircrew protective armor increases the frequency of head/armor contact. This was demonstrated in Tests 5 through 8 where three contacts occurred. The peak impact loads, however, were relatively small, being 75-80 pounds in all three cases.

The most severe head/armor contacts occurred when the helmet was worn with the new combination flak/small arms protective vest in Tests 9 through 12. Peak impact loads measured in these tests ranged from 200 pounds to 500 pounds. Examination of the high-speed film showed that these high loads are at least partly due to the construction of the armor carrier and its action during impact. This vest is more rigid than the standard carrier due to the ballistic nylon felt material used to provide fragment protection. This rigidity results in the chest armor riding slightly higher on the dummy, and prevents the armor from moving downward as rapidly under the action of the input pulse. This causes the chin to strike the armor more squarely. This is also believed to be the cause of the double peaks on the chin load traces recorded during Tests 11 and 12 (Figures 32 and 34, Appendix A). The chin strikes the armor earlier and the load reaches a peak just before the test sled has stopped. The chin remains on the load cell as the sled stops and the subsequent rebound of the sled causes the chin to be loaded again.

The head accelerations measured during the tests were in the 40-60G range in both the vertical and longitudinal axes regardless of whether head/armor contact occurred or not.

b. Biomedical Evaluation

This evaluation of the dynamic tests was conducted by the same team of medical and engineering personnel as was the original test series. The appraisal was guided by use of the electronic instrument data, posttest examination of the components, and single frame examination of the high-speed motion picture films.

In the original test series there were 30 separate impacts; contact between the upper edge of the armor and the dummy occurred in 20 of these. Of the 20 documented impacts, 19 occurred on the "face" of the dummy and one on the "neck". In the present test series, using a more realistic neck articulation in the dummy, 7 significant contacts were documented out of 12 total impacts, and all the contacts were of the "face" variety. No "neck" contacts occurred in this series.

This supports the premise that contact between the upper edge of

the armor and the wearer's face is a distinct possibility in any crash situation. It also implies that "neck" contact by the armor is rather remote. Limited medical feedback from Vietnam tends to support the preceding statements.

The loads recorded in this test series ranged from 27 to 500 pounds and the contact surface area of the load cell was 0.338 square inches.* The surface area of face contact with the armor varies from about 1.0 to 2.5 square inches.

Table I summarizes the results of recent work done in determining the tolerance of various human facial bones and neck cartilages to impact. The results of the current armor test series are included for comparison.

An anthropomorphic dummy was used in the tests described by this report, while the table summarizes data obtained using embalmed human cadavers. Extrapolation of cause-effect impact data to the human from data obtained by cadaver or dummy studies is speculative and often unsound. A similar inaccuracy exists in the transference of implications between dummy and cadaver impact data.

The following statements represent the solidification of selected experimental work and our own experience in this type of testing.

The loads received by the test dummy would have produced abrasions, lacerations, and contusions of the face, and even produce occasional broken teeth. Serious fractures would not be expected. The possibility of some degree of brain injury due to the impact cannot be assessed accurately but the probability of permanent injury appears remote at these force levels. Addition of a helmet increases the mass of the head and the impact severity. The boom microphone may contribute to some of the lacerations reported from Vietnam, but in general, the postcrash medical reports substantiate these observations. The newer style vest, in which the ceramic armor is pocketed in front of a fragment-deflecting felt, has a greater tendency to collide with the face at impact.

*Thus a 100 pound load recording would produce a stress intensity of 33.8 pounds/square inch.

TABLE I. COMPARISON OF HEAD IMPACT TOLERANCE DATA

| Investigator | Subject | Anatomic Area | Total Force (lb)* | Impact Time (sec) | Comments |
|---|---|---|---|---|---|
| Dynamic Science | Dummy | Chin | 27 to 500 (see Table II) | .025 to .040 | Impact area was .338 sq in. |
| Hodgson and Patrick, Ref. 2 and 3 | Cadaver | Maxilla, Facial | 950 to 2000 | .004 to .019 | Fractures produced at this level. The impact area was 5.2 sq in. |
| Nahum, Ref. 4 | Cadaver | Zygoma | 225 | About .010 | Produces clinically significant fracture. |
| Nahum, Ref. 4 | Cadaver | Maxilla | 175 to 210 | About .010 | Produces clinically significant fractures |
| Nahum, Ref. 4 | Cadaver | Mandible | Body 290 to 325<br>Symphysis 350 to 400 | About .010 | Produces clinically significant fractures |
| Nahum, Ref. 4 | Cadaver | Thyroid/ Cricoid Cartilage | 175 to 250 | About .010 | Produces fractures |
| Hodgson and Nakamura, Ref. 5 | Cadaver | Zygoma | 150 to 200 | .010 to .025 | Produces fractures. |

*As applied to one square inch unless otherwise noted.

5. Conclusions

Based on the data collected during this series of tests, it is concluded that:

a. The armor shows a propensity for collision with the face during moderate impact decelerations.

b. The area of head/armor contact is on the face, between the chin and nose, and the degree of probable injury is moderate to mild.

c. While the peak loads resulting from head/armor contact vary widely, the pulse shape is consistently triangular with a time base of from 0.025 second to 0.045 second.

d. The addition of a protective helmet tends to increase both the frequency and severity of head/armor contacts.

e. Head/armor impacts with armor in the new flak/small arms protective vest are more frequent and more severe than with the armor in the standard vest.

6. Recommendations

Based on the data presented in this report, the conclusions given in the previous section, and other considerations, it is recommended that:

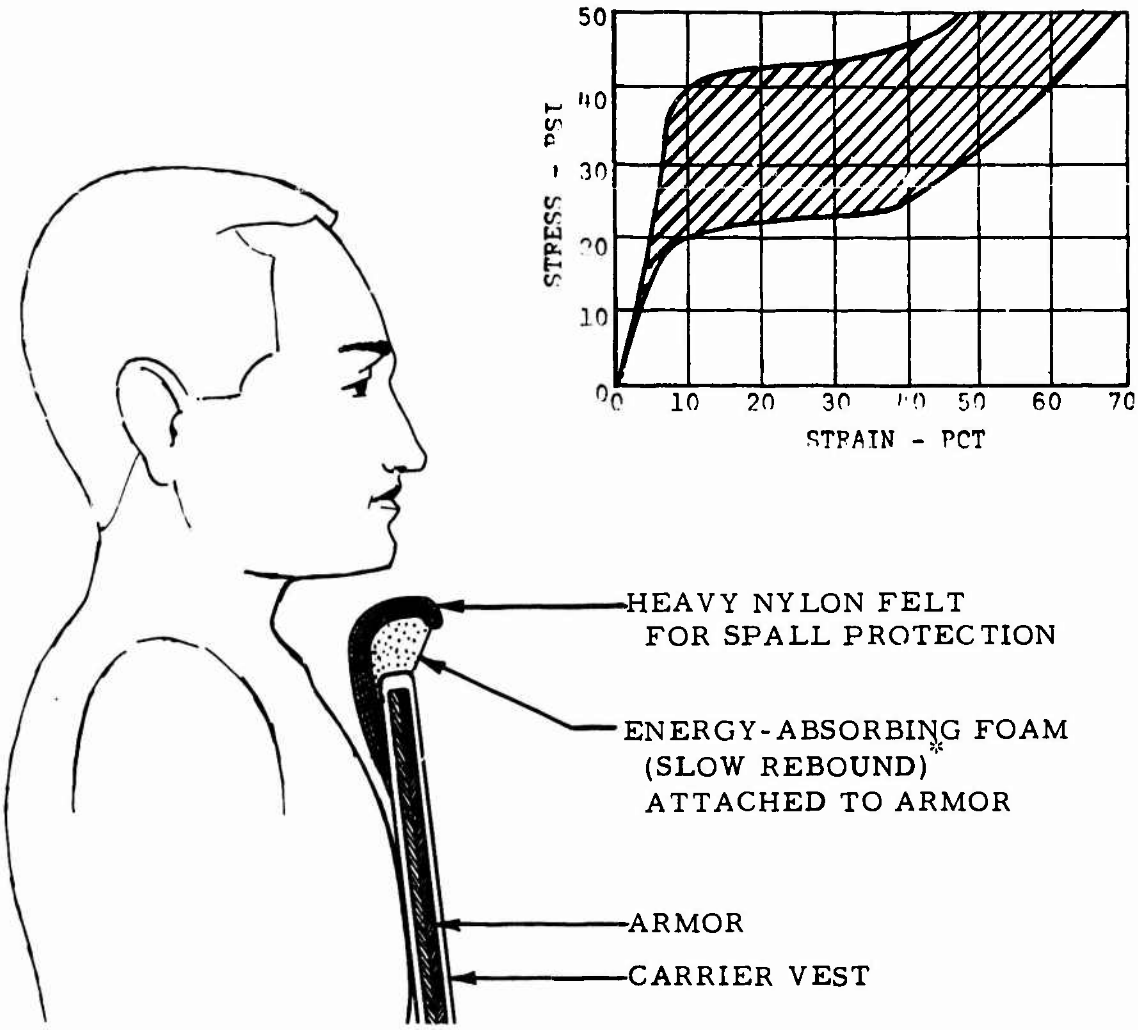
a. A padded front collar be added to the present vest carrier. This would serve to deflect spatter and spall from the exposed throat area and also serve to attenuate the impact force between the armor and the face during a crash. A suggested padding system is shown in Figure 11.

b. Armored vests be well-fitted and worn snugly, with a tight shoulder harness.

c. Continued emphasis be placed on improvement of aircrew seats. The increase in seat strength possible with simple modifications was demonstrated in this test series.

d. Consideration be given to improving the nape strap on the helmet used in this test series, in view of the failures experienced.

e. A study be made of postcrash evacuation problems of the armor




*Minimum Dimensions of Foam - 1.0 In. Thick x 1.5 In. Wide

Material - Any Slow Rebound Foam Whose Static Stress-Strain Curve Falls Within The Shaded Area of The Insert Figure.

Figure 11. Recommended Padding for Upper Edge of Armor.

wearer using live subjects, simulated injuries and actual crashed aircraft. Emphasis should be placed on the development of armor carriers and restraint systems which would minimize the effect of the armor on evacuation time.

f. Consideration be given to the inclusion of personnel armor in deceleration tests of live subjects, both humans and animals, at such facilities as the "Daisy" Track at Holloman Air Force Base. Such tests apparently have never been conducted and could lead to improved armor design.

g. An in-depth injury evaluation of accident experience in Southeast Asia be conducted to determine the after-the-fact crashworthiness of the aircrew armor. Equal emphasis should be placed on the study of direct injury and postcrash evacuation.

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## APPENDIX A

## DYNAMIC TEST REPORT

General
Test Facility and Procedure
Description of Test Items
Instrumentation
Test Conditions
Test Agenda
Test Data

## APPENDIX A
## DYNAMIC TEST REPORT

### General

The horizontal accelerator was used in this test series since previous experience[1] indicated that head/armor contacts were more severe under longitudinal acceleration. The input pulse type and seat orientations used were chosen to maximize the frequency of head/armor contacts without exceeding either the limits of human tolerance or the physical limits of the seat structure.

### Test Facility and Procedure

The horizontal accelerator, shown in Figure 12, consists of a rail-mounted sled accelerated by a falling weight. The accelerating weight is placed in the drop tower and attached to the sled carrying the test items by a cable passing through a system of pulleys. A graduated stack of paper honeycomb is placed on the impact barrier to provide the required stopping force. The sled is pulled back along the track, raising the weight in the tower to the height required to produce the desired velocity. The sled is then released and is accelerated to the desired velocity by the falling weight. The weight is stopped by a pile of sand, allowing the sled to run free to impact the paper honeycomb, producing the desired acceleration pulse.

### Description of Test Items

### Armor

Two types of personnel armor were utilized in these tests; the standard aircrew protective armor, (FSN 8470-926-1575) and the new combination flak/small arms protective vest (FSN 8470-NTK-6826).

The standard aircrew protective armor (Figure 13) consists of 2 ceramic covered fiberglass plates moulded to fit the chest and back of the wearer. These plates are contained in a vest-type canvas carrier which slips over the wearer's head and fastens at one shoulder with snaps and at the waist with "Velcro" fasteners. For these tests, only the chest armor plate was used. Total weight of the chest armor and carrier was 16 pounds.

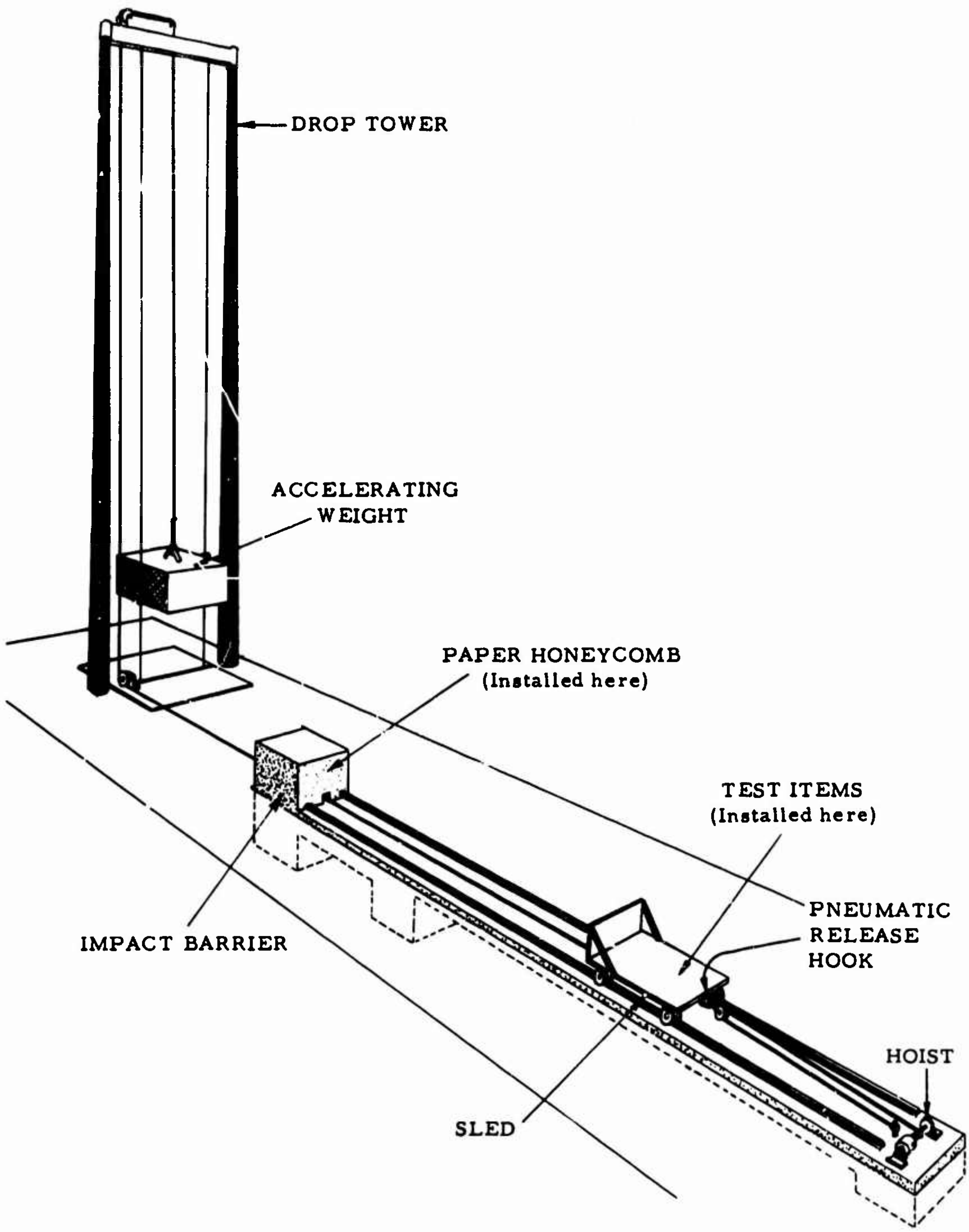



Figure 12. Drop Tower and Horizontal Accelerator Installation.

Figure 13. Vest Carrier with Front and Back Armor.
(Ba k armor at bottom of picture.)

The new combination flak/small arms protective vest (Figure 14) is similar to the standard protective armor. The chest and back armor plates are the same ceramic coated fiberglass material used in the standard protective armor. The carrier, however, contains heavy padding intended to stop low-velocity fragments. For these tests, only the chest armor plate was used with the carrier. Total weight of the vest with chest armor plate was 19 pounds.

The chest armor plate, previously modified to carry the load cell, was used with both types of protective vests. The modified plate is shown in Figure 2.

Helmet

The helmet used in this test series was the Helmet, Flying, Protective (Ballistic and Crash) (FSN 8415-935-6335). This helmet, shown installed on the test dummy in Figure 15, weighs 4-1/4 pounds without the

boom microphone and is very similar in appearance to the APH-5 helmet.

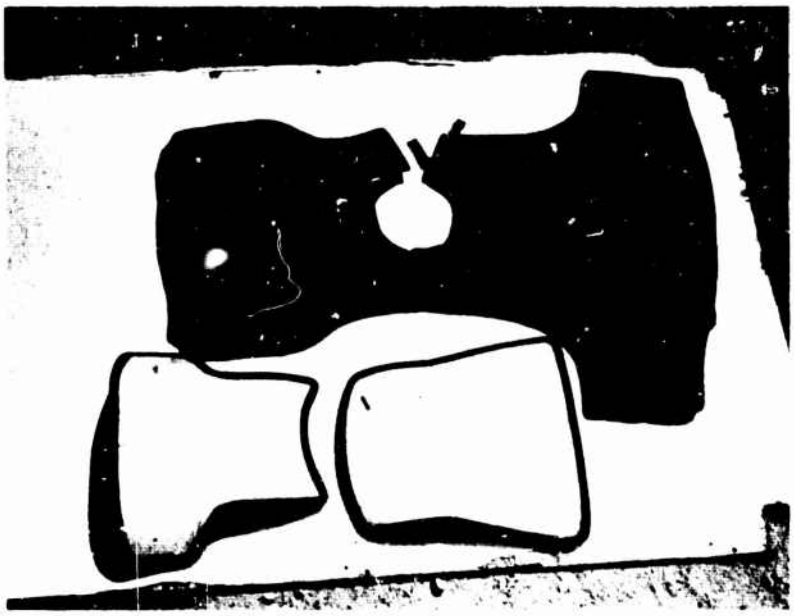


Figure 14. Combination Flak/Small Arms Protective Vest.


Figure 15. Protective Helmet Installed on Anthropomorphic Dummy.

## Seats

UH-1B/D armored seats, modified as discussed previously, were used in the test series. The seats as modifed weighed 141 pounds.

## Dummy

An Alderson F-95 dummy, modified as previously discussed, was used for all tests. The joints in the new neck assembly were adjusted so that a torque of 480 inch-pounds would rotate the joints. This torque was applied by loading a webbing strap passed around the dummy's head (at the center of gravity) and measuring this load with a spring scale. The joints were then adjusted so that an applied torque of 480-inch pounds would produce constant rotation of the joints. This is believed to be representative of the static resistance of the human neck, based on the results of previous tests[6] using live subjects. These tests also indicated that the resistance of the human neck to dynamic loading may be as much as 25 percent higher than the static resistance, provided the subject is warned and braced. Attempts to adjust the dummy neck joints to torque values higher than 480 inch-pounds resulted in erratic functioning of the joints.

## Instrumentation

### Transducers

Figure 16 illustrates the instrumentation locations in addition to the load cell mounted on the chest armor.

Instrumentation on the dummy consisted of:

1. A spinal column load transducer.

2. Vertical and longitudinal accelerometers in the head.

3. Vertical and longitudinal accelerometers in the pelvis.

Instrumentation on the seat consisted of:

1. Vertical and longitudinal accelerometers on the seat bucket.

2. A load link in each half of the lap belt.

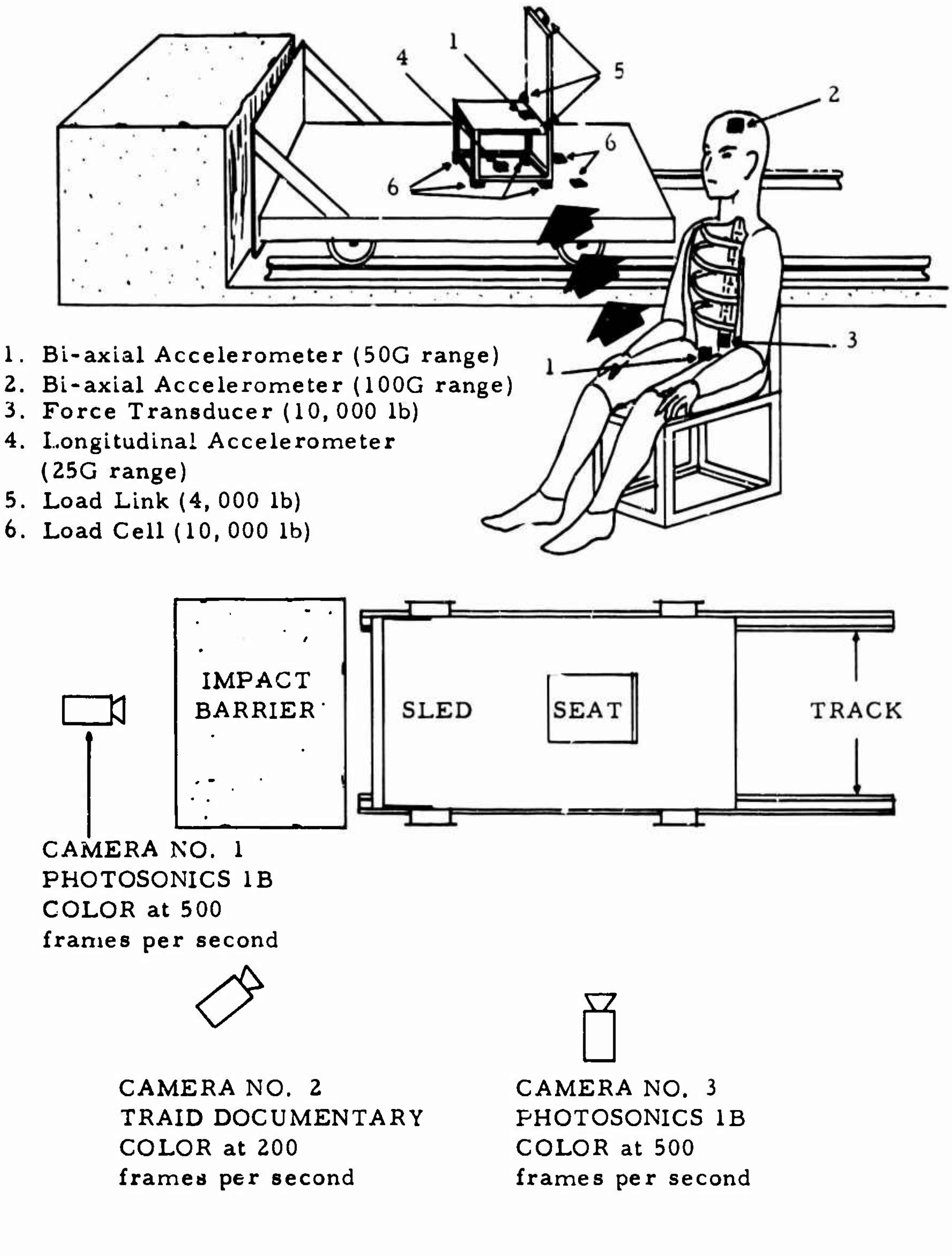



Figure 16. Horizontal Accelerator Instrumentation and Camera Layout.

3. A load link in the shoulder harness between the inertia reel and the neck yoke.

4. A load cell under each seat leg.

5. A load link behind each rear seat leg to measure the shear load parallel to the floor.

An accelerometer was mounted on the longitudinal axis of the sled to measure the input acceleration.

## Data Recording System

The data from all transducers, except the armor mounted load cell, were recorded on a magnetic tape recording system. This system utilizes a constant bandwidth FM/FM multiplex modulation technique in which the analog signal from the transducer is converted by a subcarrier oscillator into a frequency deviation proportional to the amplitude of the input signal. Seven of these subcarrier oscillator outputs are combined in a mixer amplifier and the resulting composite signal recorded on one track of a 14-track tape recorder.

The output from the armor mounted load cell was fed through a charge amplifier to an oscilloscope as shown by the block diagram in Figure 17. The trace on the oscilloscope was recorded photographically using an integrally mounted Polaroid camera.

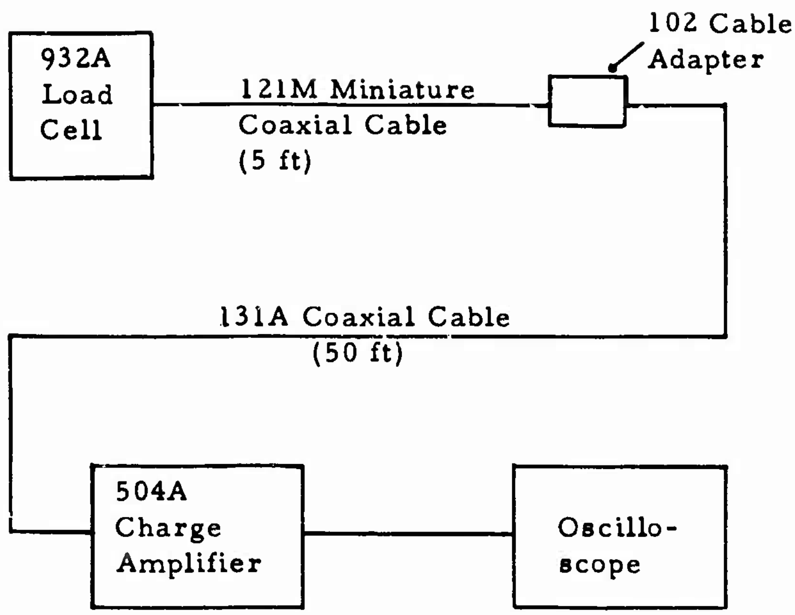
In order to determine the exact point of contact between the head and the armor, the top of the load cell was heavily coated with black enamel just prior to each test. Transfer of the wet enamel to the dummy's head during impact served to locate the point of contact.

## Photographic Coverage

Three high-speed motion picture cameras were mounted as shown in Figure 16 to provide photographic coverage of the action of the dummy and armor during impact.

## Electronic Data Processing System

The data recorded on the magnetic tape recorder system was recovered by utilizing a compatible data processing system. In this system, a playback tape recorder removes the composite signal from each track of the test tape and processes it through a series of FM




Note: Numbered parts by Kistler Instrument Corporation.

Figure 17. Block Diagram - Data Acquisition System For Armor Mounted Load Cell.

discriminators which separate the composite signal into various subcarrier frequency deviations. These frequency deviations are then converted to an analog signal which is recorded directly on an oscillograph plotter. The resulting oscillograph record is then processed and is available as a scaled analog plot of the recorded data.

All instrumentation is identified by type and manufacturer in Appendix B.

## Test Conditions

All tests were conducted under the same impact conditions with the same seat orientation as follows:

### Impact Conditions:

| | | |
|---|---|---|
| Pulse shape | - | Triangular |
| Peak acceleration | - | 15G |
| Velocity change | - | 30 ft/sec |

Seat Orientation:

| | | |
|---|---|---|
| Pitch angle | - | 15 degrees up |
| Roll angle | - | 0 degrees |
| Yaw angle | - | 0 degrees |

Figure 18 shows a typical seat installation prior to testing.

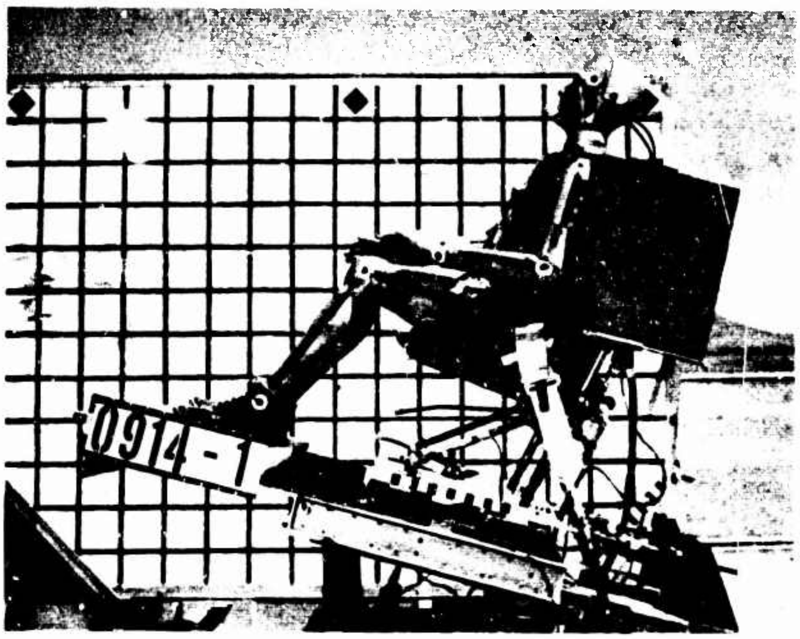



Figure 18. Typical Seat Installation.

Test Agenda

A total of 12 tests were conducted using 3 different armor/helmet configurations as follows:

| | | |
|---|---|---|
| Tests 1 through 4 | - | Standard aircrew protective armor without helmet |
| Tests 5 through 8 | - | Standard aircrew protective armor with helmet |
| Tests 9 through 12 | - | New combination flak/small arms protective vest with helmet. |

## Test Data

### General

In the following discussion of the dynamic test series, each block of 4 identical tests will be discussed separately. All 3 blocks of tests were conducted under the same impact conditions using the same seat orientation with the only change between blocks being the armor and helmet worn by the dummy. The traces of the head impact loads are presented in the discussion of the appropriate block of tests. Table II presents a summary of the head and sled impact data for all tests.

All other measurements previously listed under "Test Instrumentation" were made during each of the 12 tests. One test has been selected from each block of 4 tests as being representative of that block and the data from these 3 tests presented. Table III lists the peak values of each measurement while the complete data traces are presented in Appendix C.

### Seat Performance

No major seat failure occurred during the test series. Seat damage was limited to minor deformation of the forward end of the seat slide, minor bending of the front cross tube and bending of the seat back.

### Action of the Personnel Armor

The personnel armor remained in place during all tests with no damage to the armor, the carrier vest or the restraint harness.

### Tests 1 Through 4

In these tests, the dummy was fitted with the standard aircrew protective armor with no helmet as shown in Figure 19.

Only 1 significant head/armor contact occurred during these 4 tests. This took place during Test 4, when the load cell registered a peak load of 27 pounds due to impact of the chin. Figure 20 shows a posttest front view of the dummy. The black mark on the chin indicates the impact point. Figure 21 shows the trace resulting from this impact. No significant difference in head accelerations was noted between this test and those in which no head/armor contact occurred.

Minor contact occurred during Tests 2 and 3, however, the load was insufficient to trigger the load cell.

TABLE II. SUMMARY OF HEAD/ARMOR IMPACT DATA

| Test | Contact Location | Maximum Load (lb) | Sled Accel. (Long.) (G) | Head Accel. (Long.) (G) | Head Accel. (Vert.) (G) | Pulse Shape | Duration (sec) |
|---|---|---|---|---|---|---|---|
| 1 | None | - | 15.4 | 52.5 | 49.5 | - | - |
| 2 | None | - | 16.5 | 57.2 | 50.3 | - | - |
| 3 | None | - | 15.6 | 59.6 | 57.5 | - | - |
| 4 | Chin | 27 | 16.4 | 53.3 | 59.8 | Triangle | 0.040 |
| 5 | Chin | 80* | 16.4 | 30.3 | 42.5 | Triangle | 0.040 |
| 6 | Chin | 82 | 15.7 | 41.0 | 57.0 | Triangle | 0.030 |
| 7 | Chin | 75 | 14.9 | 24.1 | 35.2 | Triangle | 0.035 |
| 8 | None | - | 14.5 | 40.9 | 40.9 | - | - |
| 9 | Chin | 475* | 16.5 | 54.0 | 50.1 | Triangle (Double Peak) | 0.045 |
| 10 | None | - | 13.7 | 46.4 | 39.5 | - | - |
| 11 | Chin | 200 | 13.9 | 51.4 | 43.6 | Triangle | 0.025 |
| 12 | Chin | 500* | *** | *** | *** | Triangle (Double Peak) | 0.030** |

* Peaks extrapolated
** Failure of output cable ended trace prematurely, duration estimated
*** Instrumentation malfunction

| TABLE III. SUMMARY OF DATA | | | | |
|---|---|---|---|---|
| | | Test Number | | |
| Measurement | Unit | 4 | 6 | 11 |
| Sled Acceleration (Long.) | G | 16.4 | 15.7 | 13.9 |
| Seat Pan Accel. (Long.) | G | 19.0 | 20.4 | 14.4 |
| Occupant Pelvic Accel. (Long.) | G | 30.7 | 21.8 | 24.2 |
| Occupant Head Accel. (Long.) | G | 63.3 | 41.0 | 51.4 |
| Seat Pan Accel. (Vert.) | G | 11.8 | 9.5 | 10.0 |
| Occupant Pelvic Accel. (Vert.) | G | 13.8 | 13.4 | 11.9 |
| Occupant Head Accel. (Vert.) | G | 59.8 | 57.0 | 43.6 |
| Occupant Vertebra Load | lb | * | 1690 | 1410 |
| R/H Front Seat Leg Load (Vert.) | lb | 3680 | 3820 | 3590 |
| L/H Front Seat Leg Load (Vert.) | lb | 4260 | 4250 | 3880 |
| R/H Rear Seat Leg Load (Vert.) | lb | 3000 | 3220 | 3320 |
| L/H Rear Seat Leg Load (Vert.) | lb | 3300 | 2950 | 2890 |
| R/H Seat Load (Horiz.) | lb | 1950 | 1790 | 1500 |
| L/H Seat Load (Horiz.) | lb | 2720 | 2700 | 2540 |
| R/H Lap Belt Load | lb | 950 | 926 | 840 |
| L/H Lap Belt Load | lb | 900 | 750 | 630 |
| Shoulder Harness Load | lb | 1180 | 1400 | 1250 |

* No record.

Due to a malfunction of one track in the data recording system, no occupant vertebra loads were recorded.

Tests 5 Through 8

For these tests the dummy was wearing the standard aircrew protective armor with the protective helmet as shown in Figure 22.

Significant head/armor contacts occurred in 3 of the 4 tests in this block. All contacts occurred on the chin of the dummy and produced

Figure 19. Dummy Fitted With Standard Aircrew Protective Armor for Tests 1 Through 4.

Figure 20. Posttest View - Test 4. (Black mark on chin is impact point.)

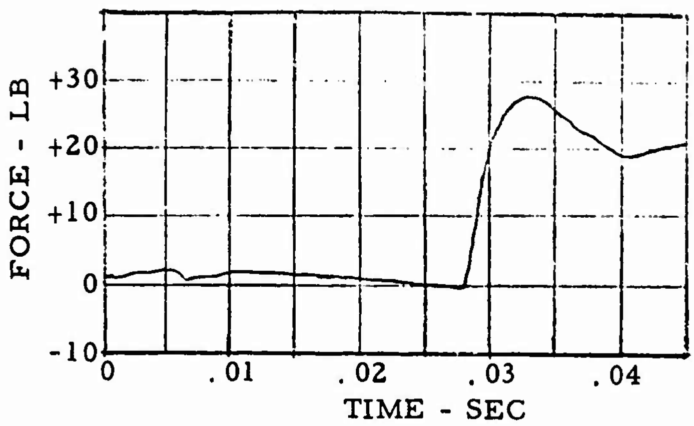



Figure 21. Chin Impact Load - Test 4.

Figure 22. Dummy Fitted With Standard Aircrew Protective Armor and Helmet for Tests 5 Through 8.

loads of about 80 pounds. The resulting traces and posttest photographs showing impact locations are shown in Figures 23 through 27. No posttest photograph is available from Test 5.

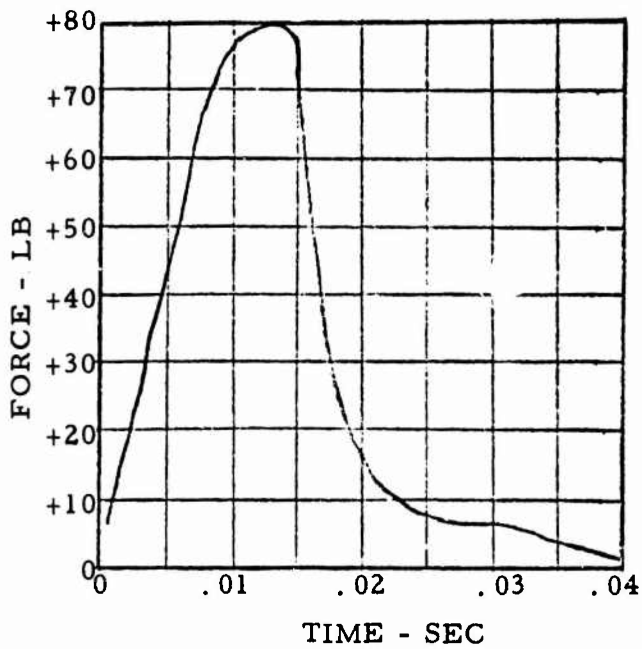



Figure 23. Chin Load Trace - Test 5. (Peak extrapolated.)


Figure 24. Posttest View - Test 6.
(Black mark on chin is contact point.)

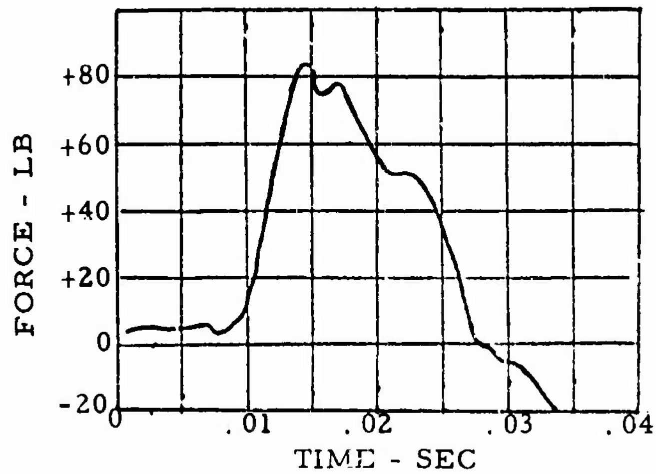



Figure 25. Chin Load Trace - Test 6.


Figure 26. Posttest View - Test 7.
(Black mark on chin is contact point.)

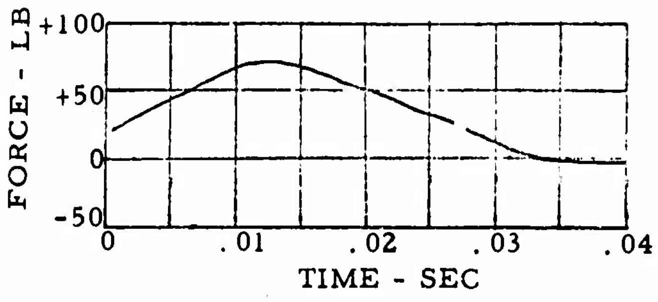



Figure 27. Chin Load Trace - Test 7.

No contact was recorded during Test 8.

Some difficulty was experienced with helmet retention during this block of tests. The nape strap failed during Test 6, allowing the helmet to come completely free. The nape strap was replaced with a length of 1-inch wide webbing, which performed fairly well for the remainder of the tests. Again, no significant difference in head accelerations was noted between the tests in which head/armor contact occurred and the one test where no contact occurred.

## Tests 9 Through 12

In this block of tests, the dummy was fitted with the new combination flak/small arms protective vest and the protective helmet as shown in Figure 15.

Three significant head/armor impacts occurred during this block of tests. In all 3, the contact point was on the chin. The resulting loads ranged from 200 pounds to 500 pounds. The head accelerations were not materially different in any of the tests, regardless of whether or not head/armor contact occurred. Test 10 was the only test in which no significant contact occurred.

Figures 28 through 33 show posttest views and load traces from the tests involving head/armor contact.

Some problems with helmet retention were encountered during this block of tests. Although the helmet did not come completely off at any time, examination of the high-speed film showed that the helmet rotated forward on the head during each test. In one case, this rotation was due to slippage of the rear portion of the dummy's "scalp".

Figure 28. Posttest View - Test 9.
(Black mark on chin is contact point.)

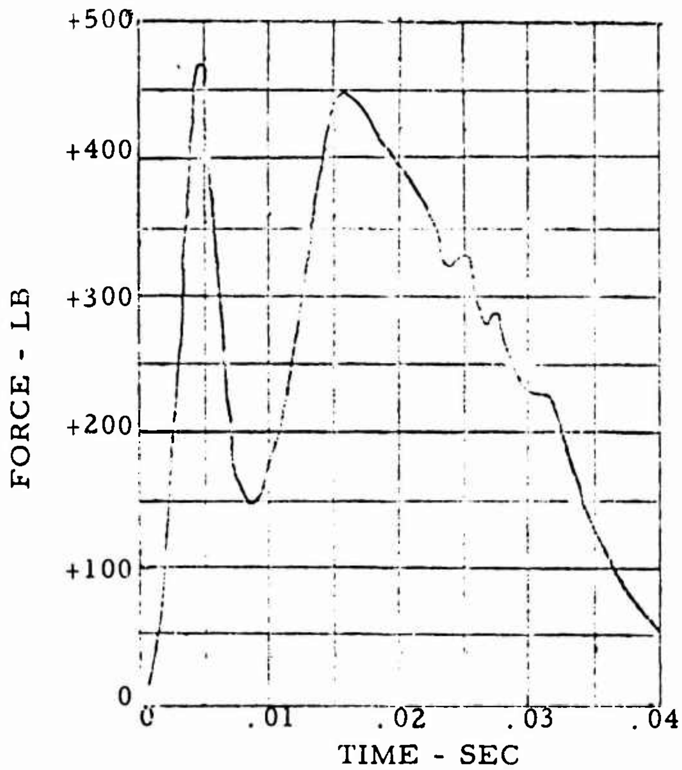



Figure 29. Chin Load Trace - Test 9. (Peaks extrapolated.)

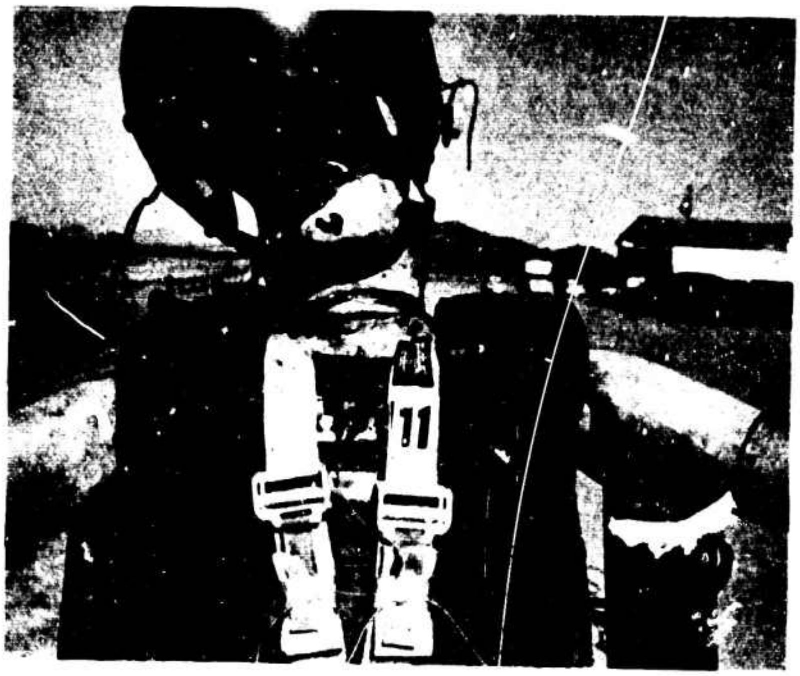


Figure 30. Posttest View - Test 11.
(Black mark on chin is contact point.)

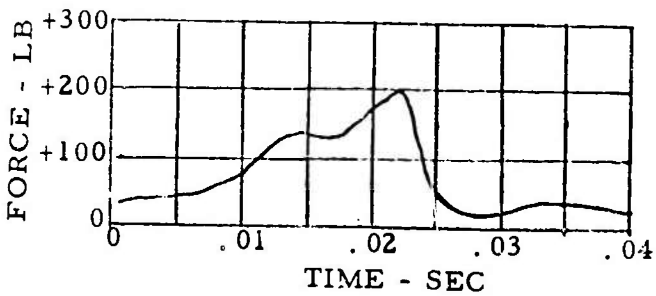



Figure 31. Chin Load Trace - Test 11.

Figure 32. Posttest View - Test 12.
(Black mark on chin is contact point.)

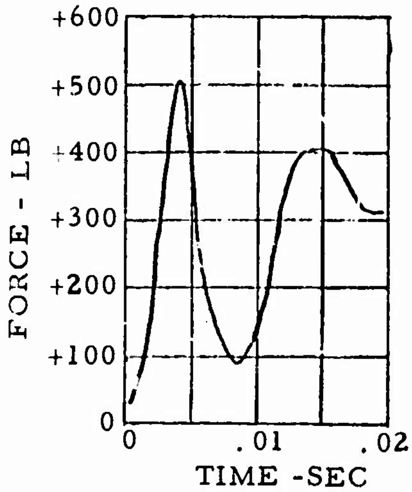



Figure 33. Chin Load Trace - Test 12.
(Failure of output cable caused trace termination.)

# APPENDIX B

## INSTRUMENTATION

### Data Recording System

## APPENDIX B
## INSTRUMENTATION

The instruments listed in Table IV, exclusive of the cameras and the Kistler 932-A load cell, are the input media for the magnetic tape recording system that consists of the following components:

| Item | Manufacturer and Model |
|---|---|
| Tape Transport | Weber 10-110 |
| Electronic Module Housing | Weber 60-117 |
| Voltage Regulator | Weber 43-106 |
| Inverter | Weber 41-111 |
| Bias Oscillator | Weber 30-109 |
| Record Amplifiers | Weber 20-108 |
| Balance and Sensitivity Calibration Equipment | Dynamic Science |
| Timing Signal Generator | Dynamic Science |
| Ni-Cad Batteries | Sonotone |

The signals from the instruments are fed into the self-contained signal-conditioning circuits and then recorded on 1-inch magnetic tape at 60-inches per second. Each signal is recorded on two tracks for reliability. Timing and correlation are also recorded.

The signal from the Kistler 932-A load cell was fed through 55 feet of low-noise coaxial cable into a Kistler 504-A charge amplifier. The amplified signal was then used to trigger a Tektronix Model 502 dual beam oscilloscope as shown by the block diagram in Figure 17. The resulting trace was rec rded on Polaroid film by a Tekronix Model C-12 oscilloscope camera.

| TABLE IV. INSTRUMENTATION | | | |
|---|---|---|---|
| Instrument | Type or Model | Manufacturer | Location |
| Transducer | 10,000 lb. | Dynamic Science | Vertebra<br>Seat Legs |
| Accelerometer | A-5-25, -50 | Statham | Dummy Pelvis<br>Sled<br>Seat Bucket |
| Load Link | 4,000 lb. | Dynamic Science | Shoulder Harness<br>Lap Belt |
| Load Cell | 932 A | Kistler | Chest Armor Plate |
| Camera | 1B | Photosonics | Impact Barrier |
| Camera | 200V | Traid | Impact Barrier |

## APPENDIX C

## ACCELERATION - TIME AND FORCE - TIME HISTORIES

## APPENDIX C
## ACCELERATION - TIME AND FORCE - TIME HISTORIES

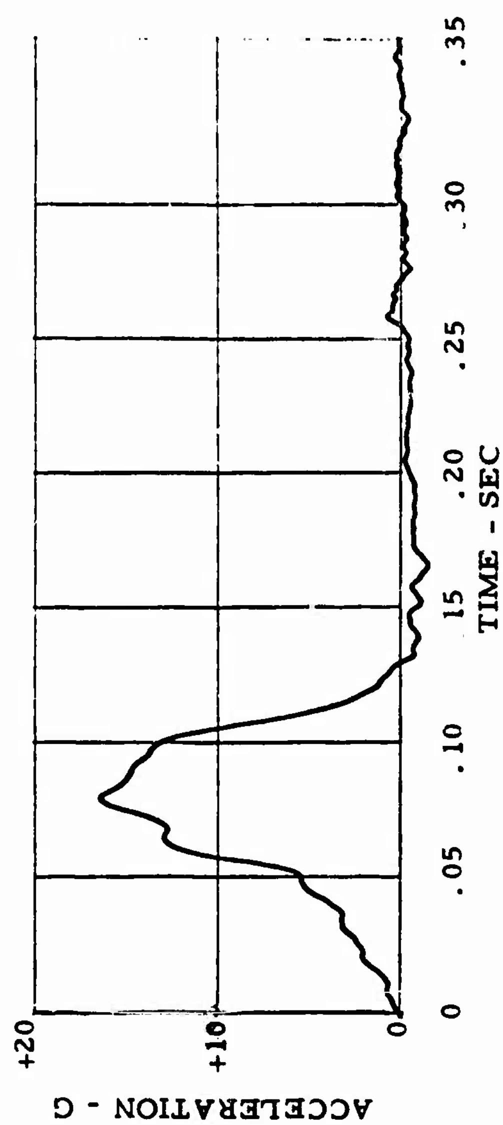



Figure 34. Test 4 Acceleration - Time History, Sled Acceleration (Longitudinal).

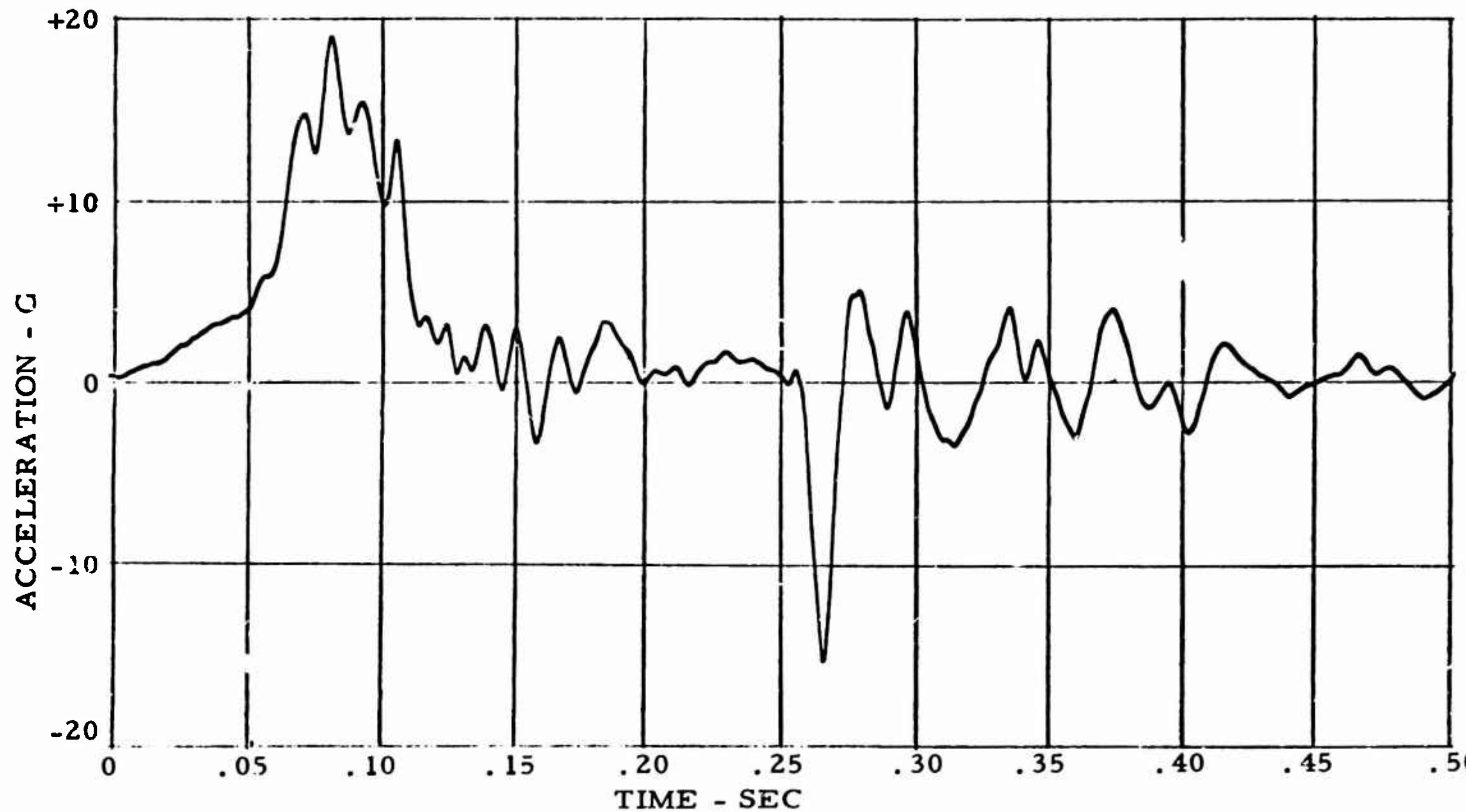



Figure 35. Test 4 Acceleration - Time History, Seat Pan Acceleration (Longitudinal).

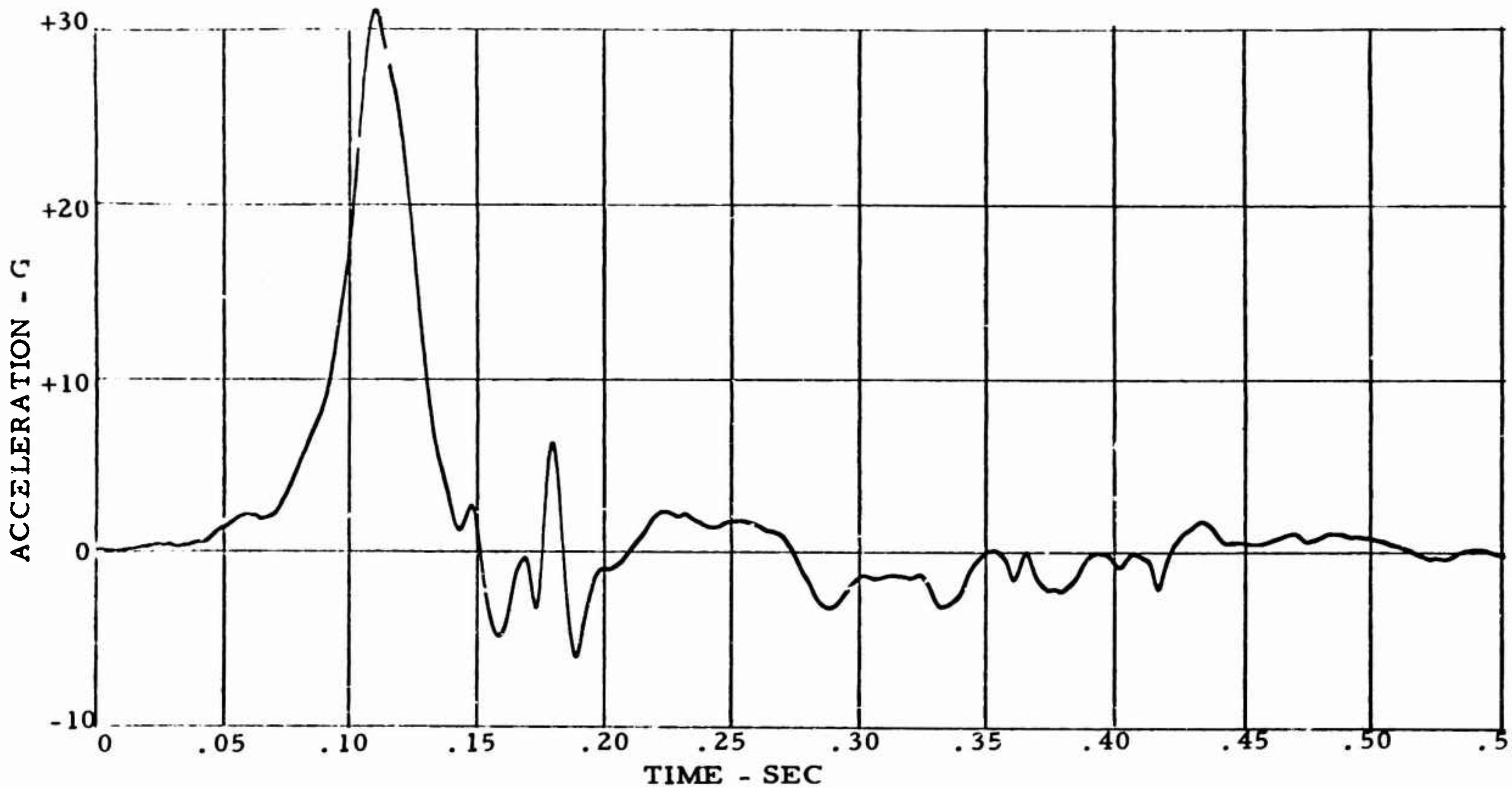



Figure 36. Test 4 Acceleration - Time History, Occupant Pelvic Acceleration (Longitudinal).

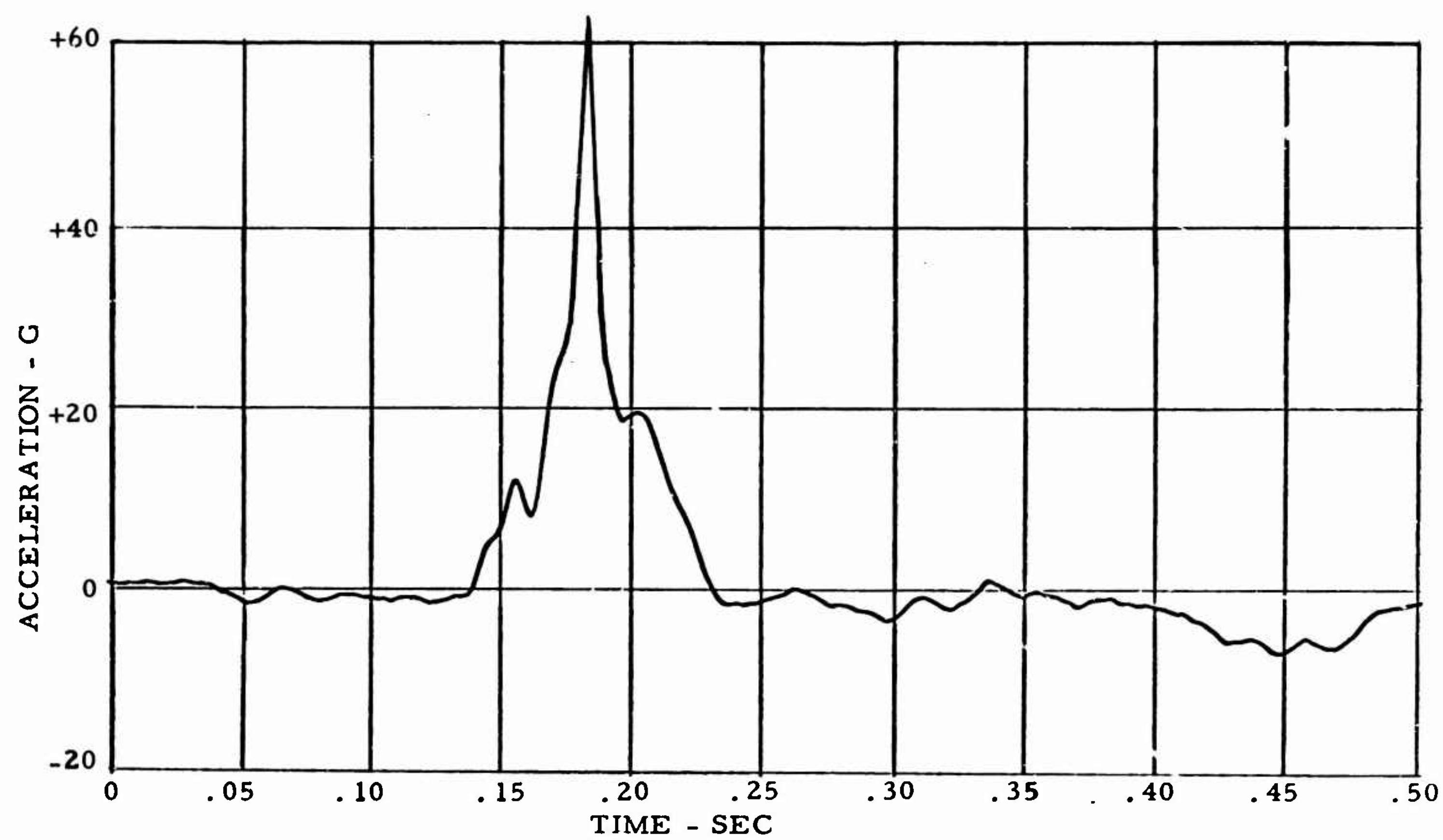



Figure 37. Test 4 Acceleration - Time History, Occupant Head Acceleration (Longitudinal).

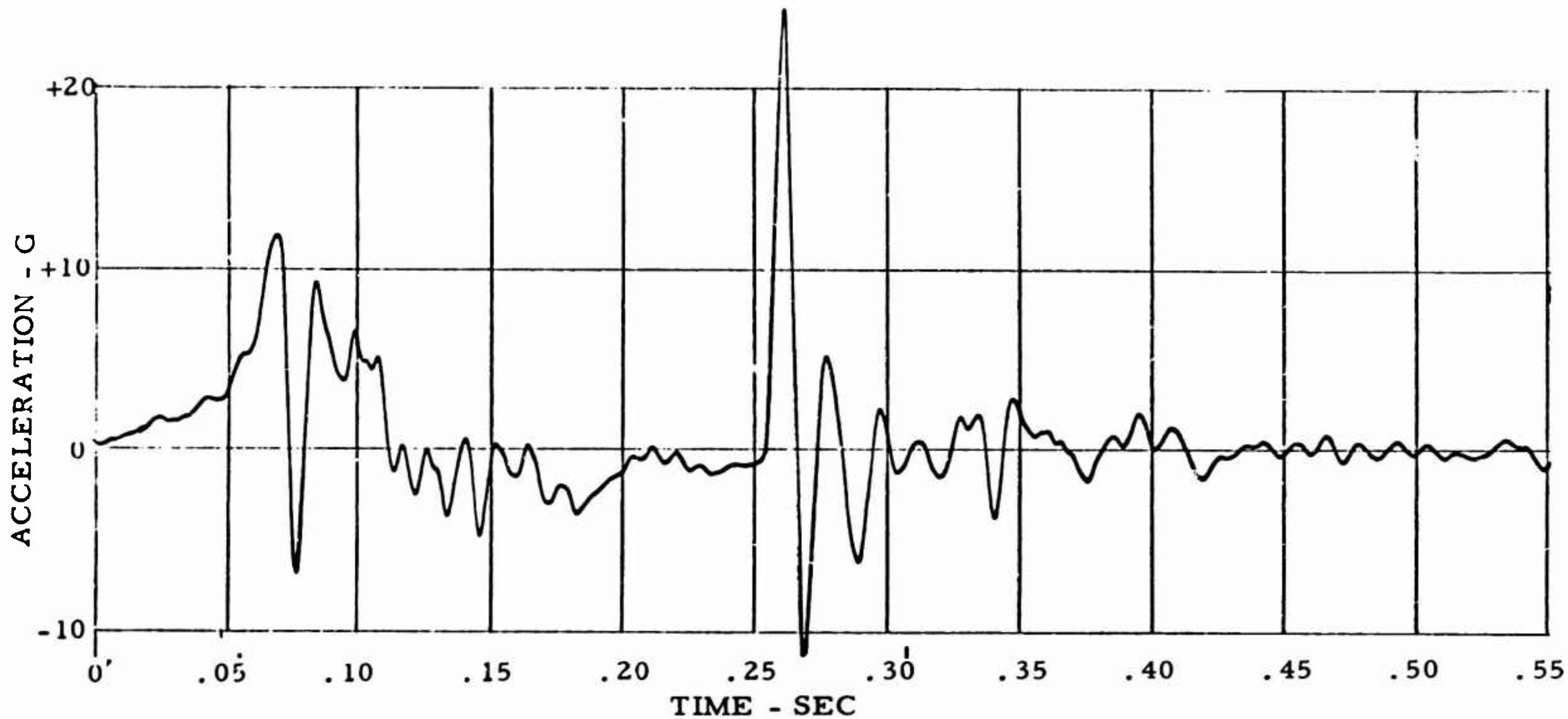



Figure 38. Test 4 Acceleration - Time History, Seat Pan Acceleration (Vertical).

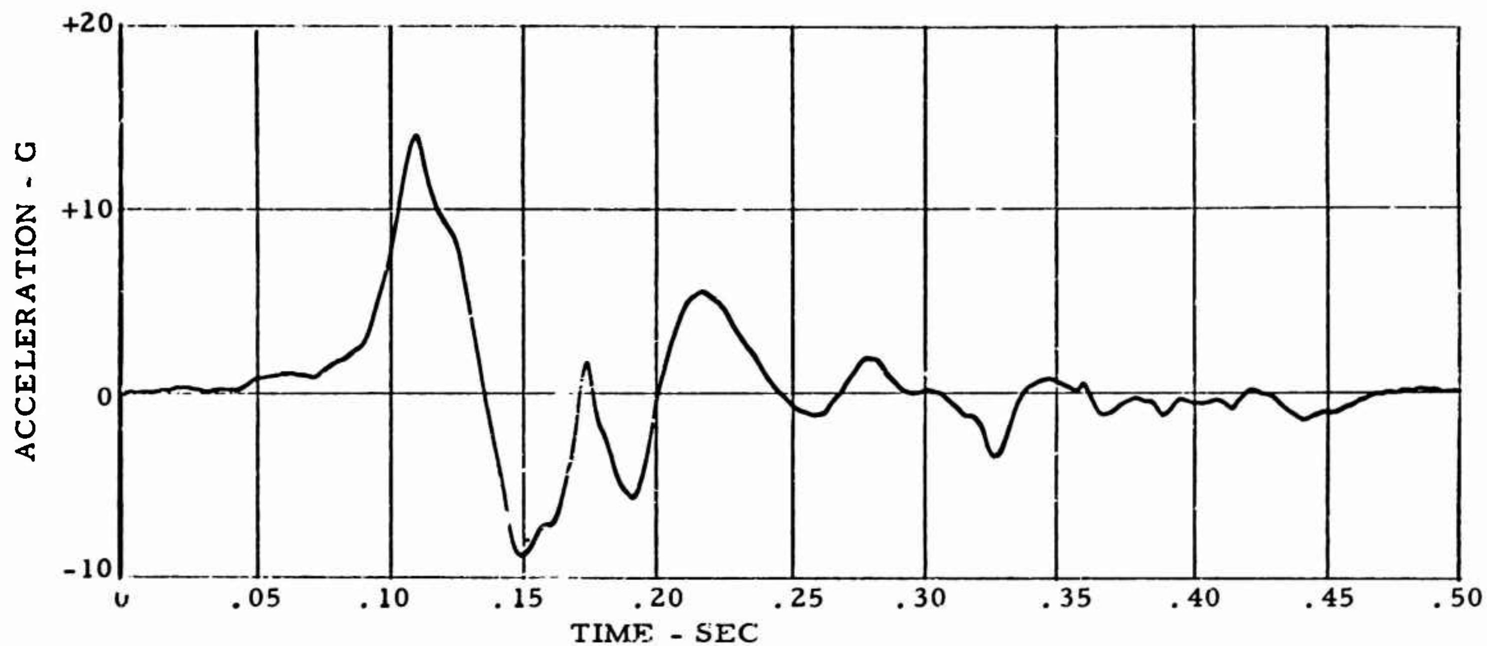



Figure 39. Test 4 Acceleration - Time History, Occupant Pelvic Acceleration (Vertical).

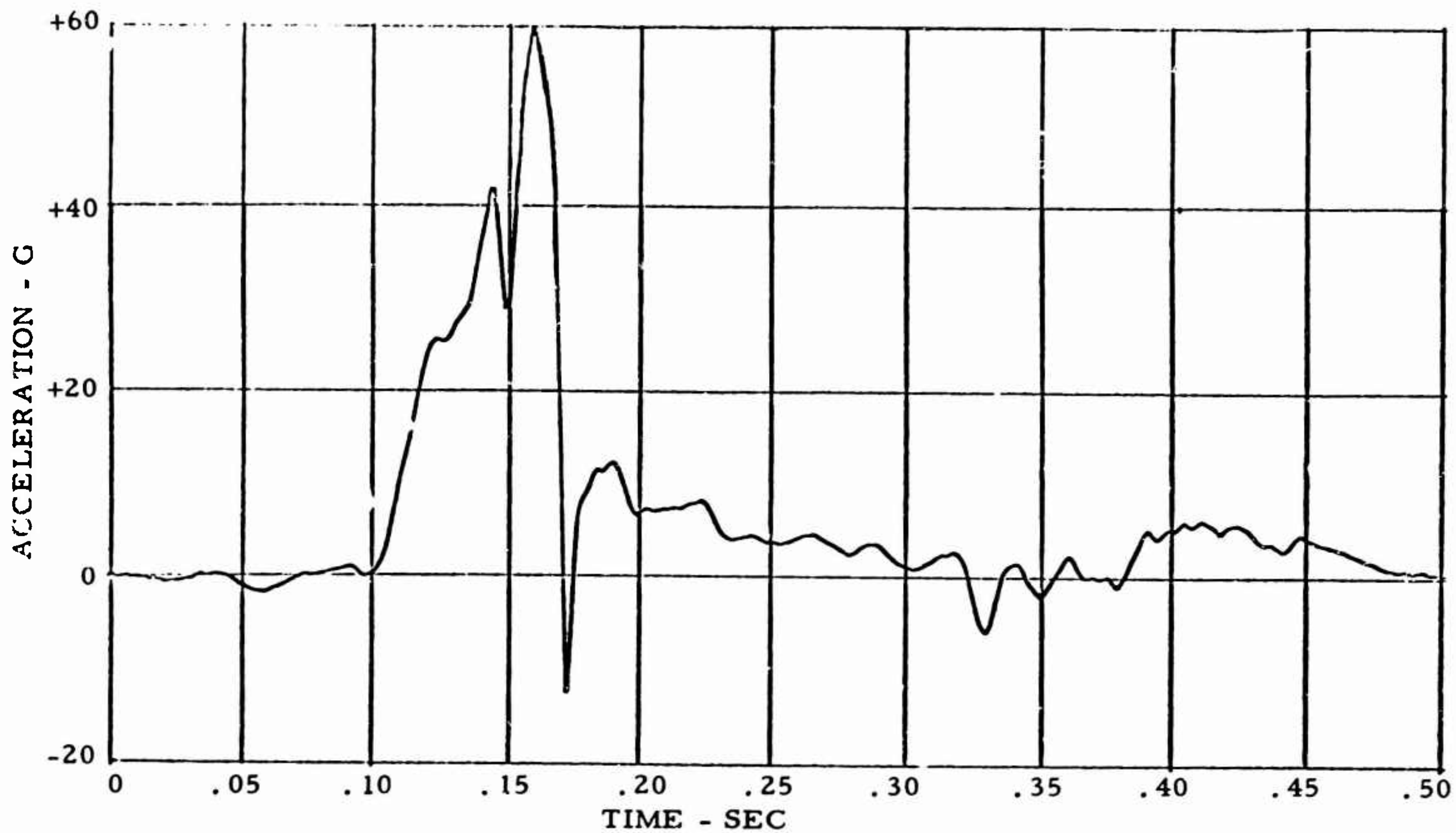



Figure 40. Test 4 Acceleration - Time History, Occupant Head Acceleration (Vertical).

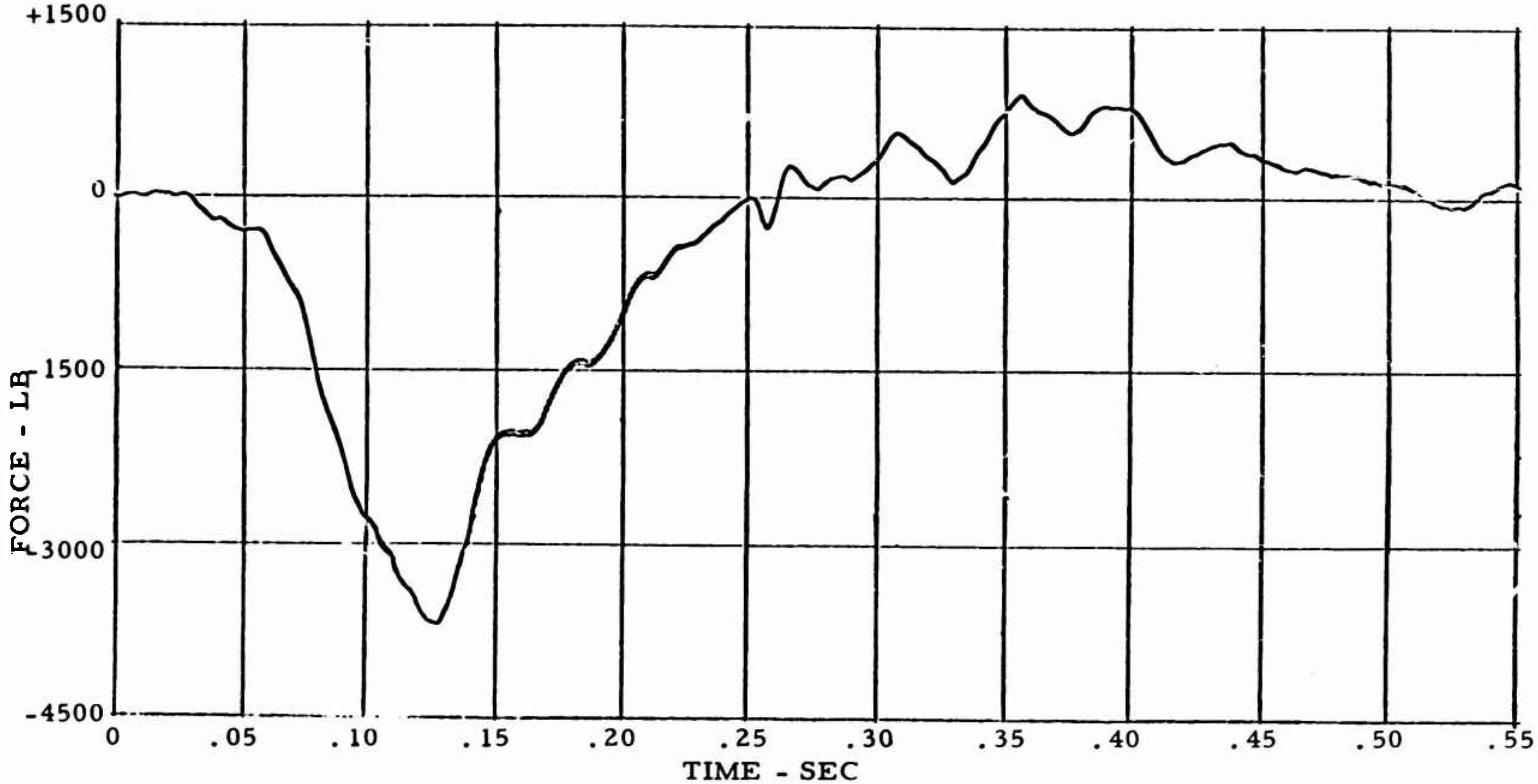



Figure 41. Test 4 Force - Time History, Right Hand Front Seat Leg Load (Vertical).

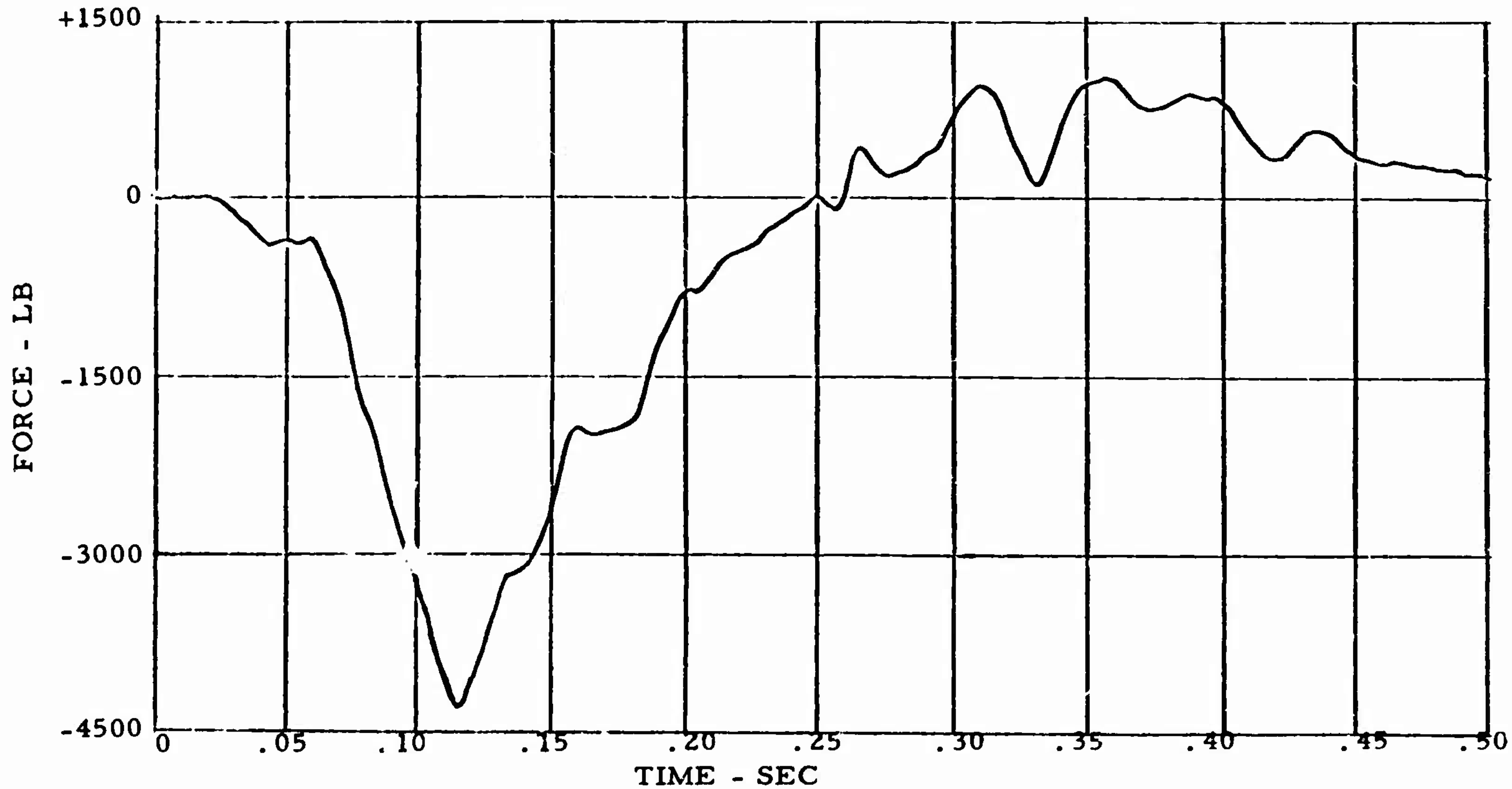



Figure 42. Test 4 Force - Time History, Left Hand Front Sea Leg Load (Vertical).

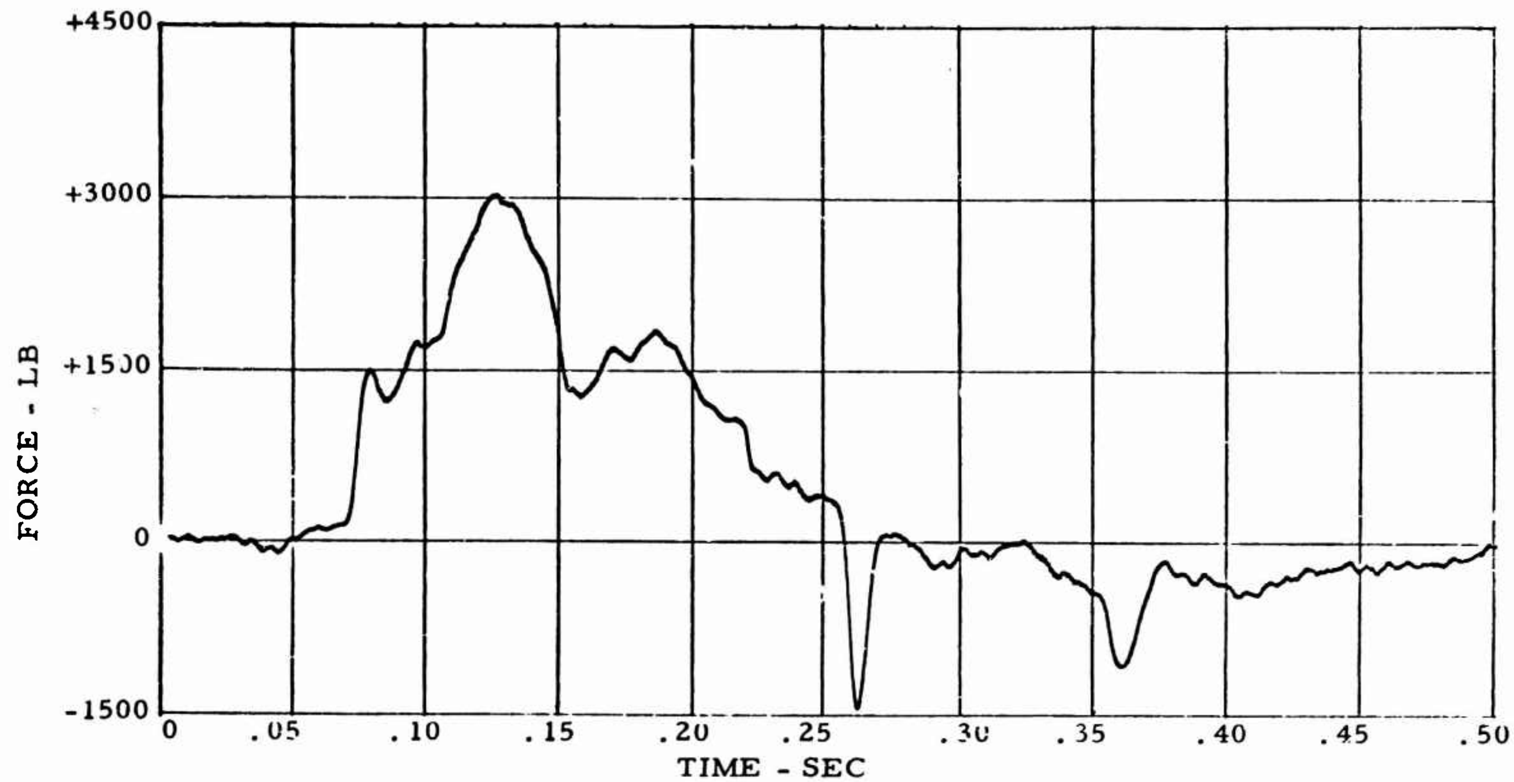



Figure 43. Test 4 Force - Time History, Right Hand Rear Seat Leg Load (Vertical).

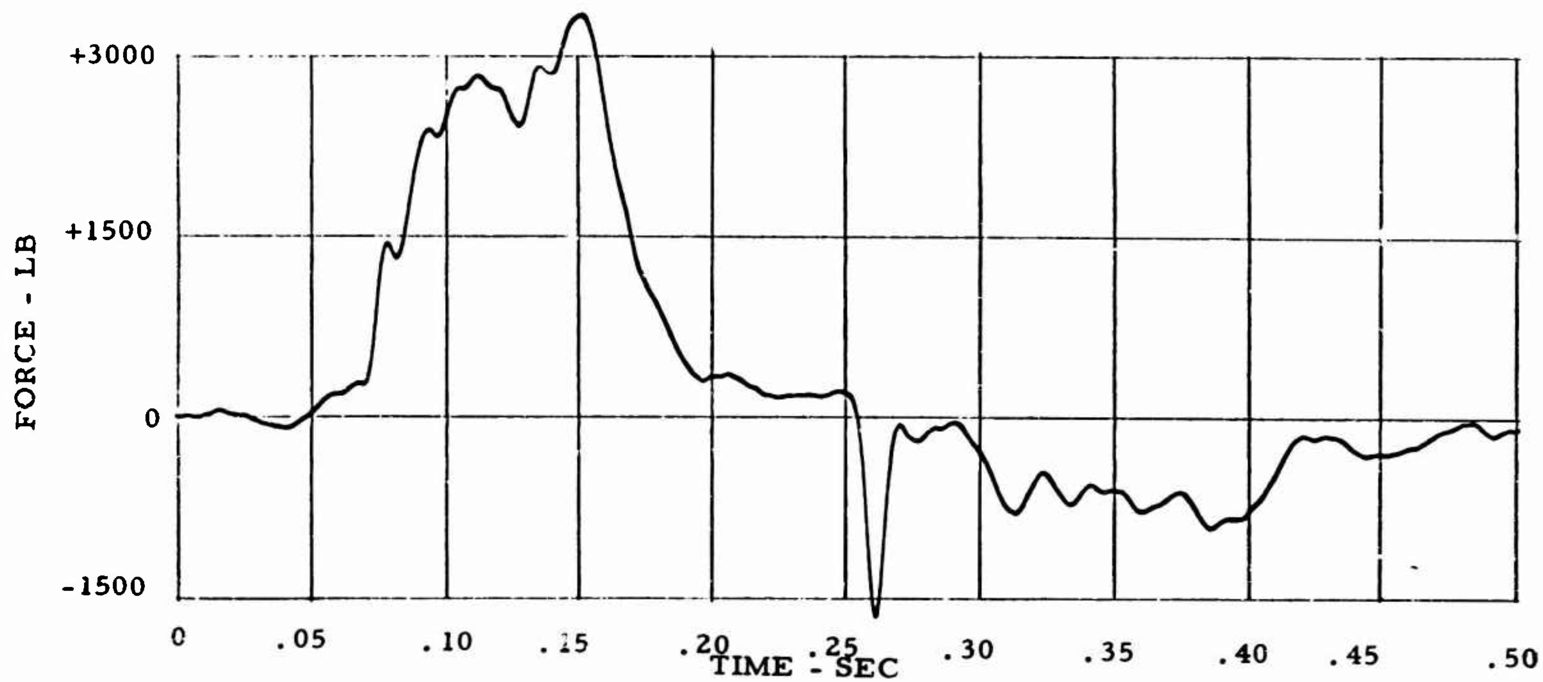



Figure 44. Test 4 Force - Time History, Left Hand Rear Seat Leg Load (Vertical).

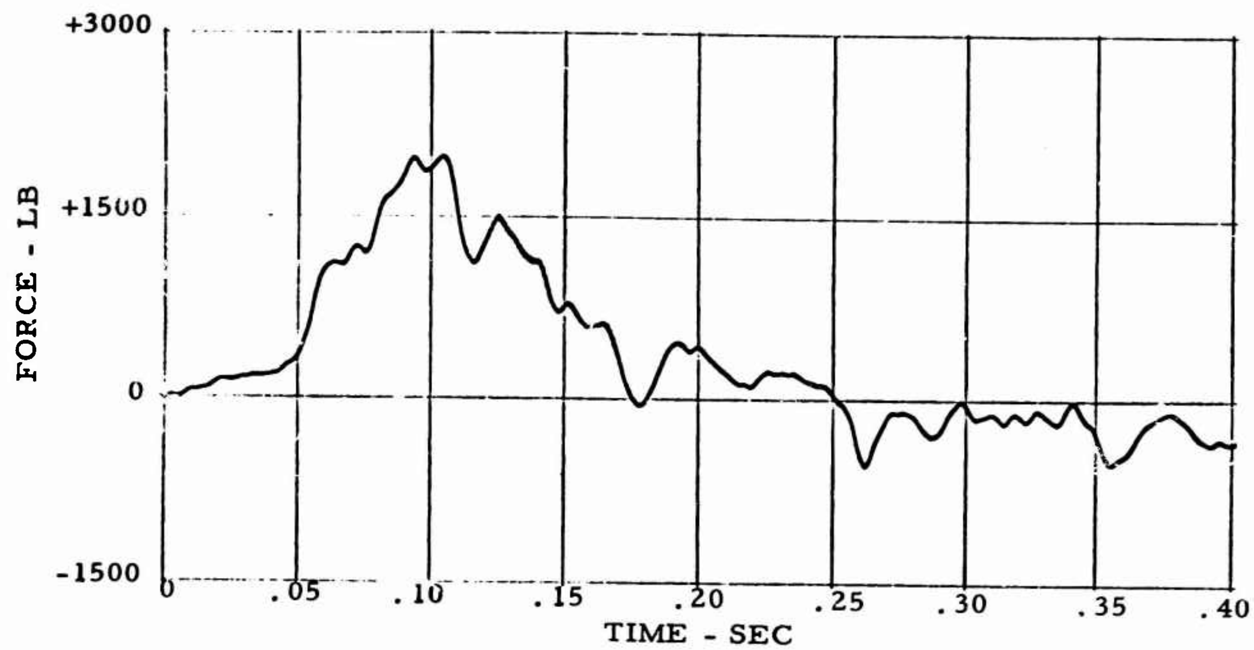



Figure 45. Test 4 Force - Time History, Right Hand Seat Load (Horizontal).

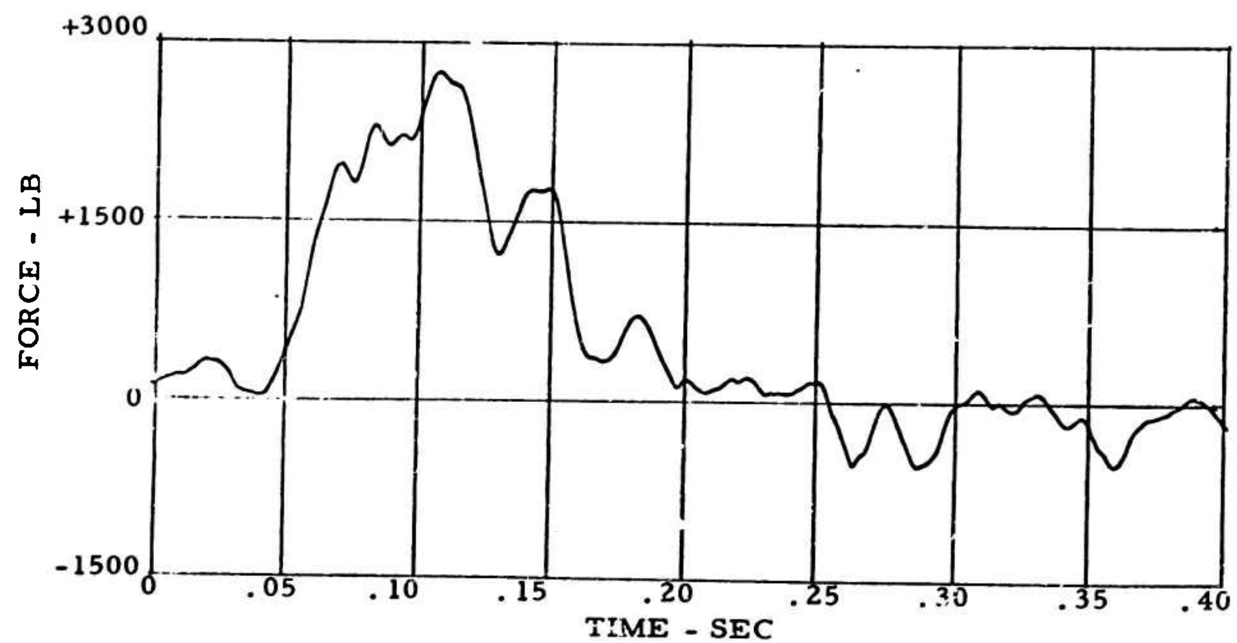



Figure 46. Test 4 Force - Time History, Left Hand Seat Load (Horizontal).

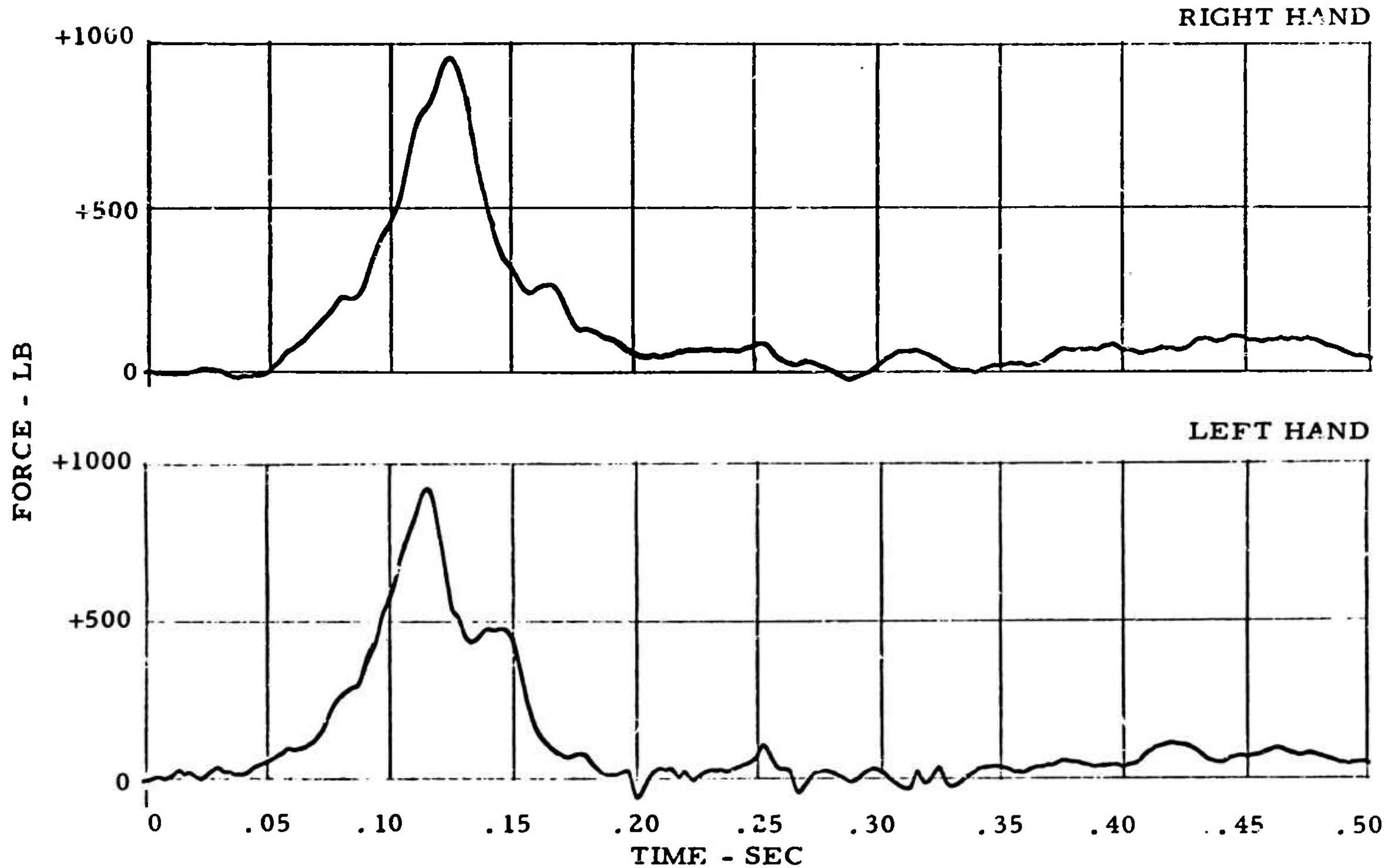



Figure 47. Test 4 Force - Time Histories, Lap Belt Loads.

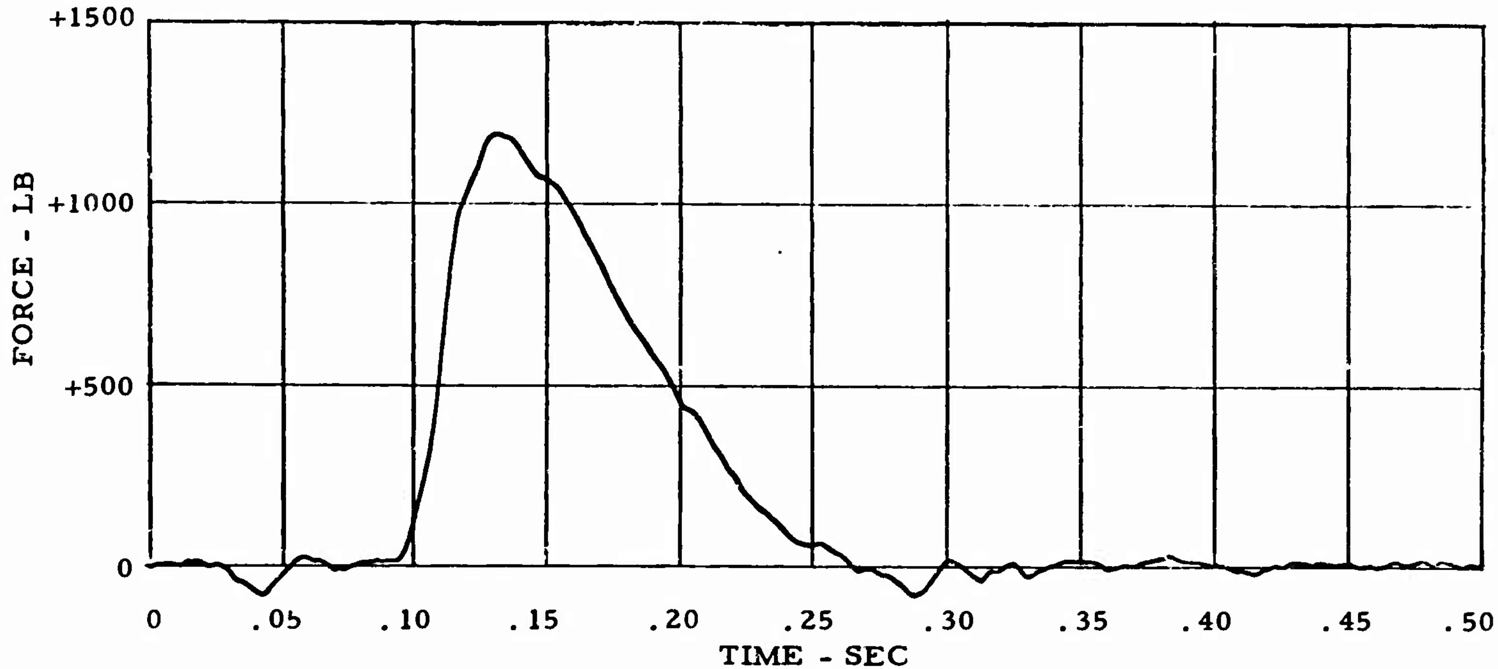



Figure 48. Test 4 Force - Time History, Shoulder Harness Load.

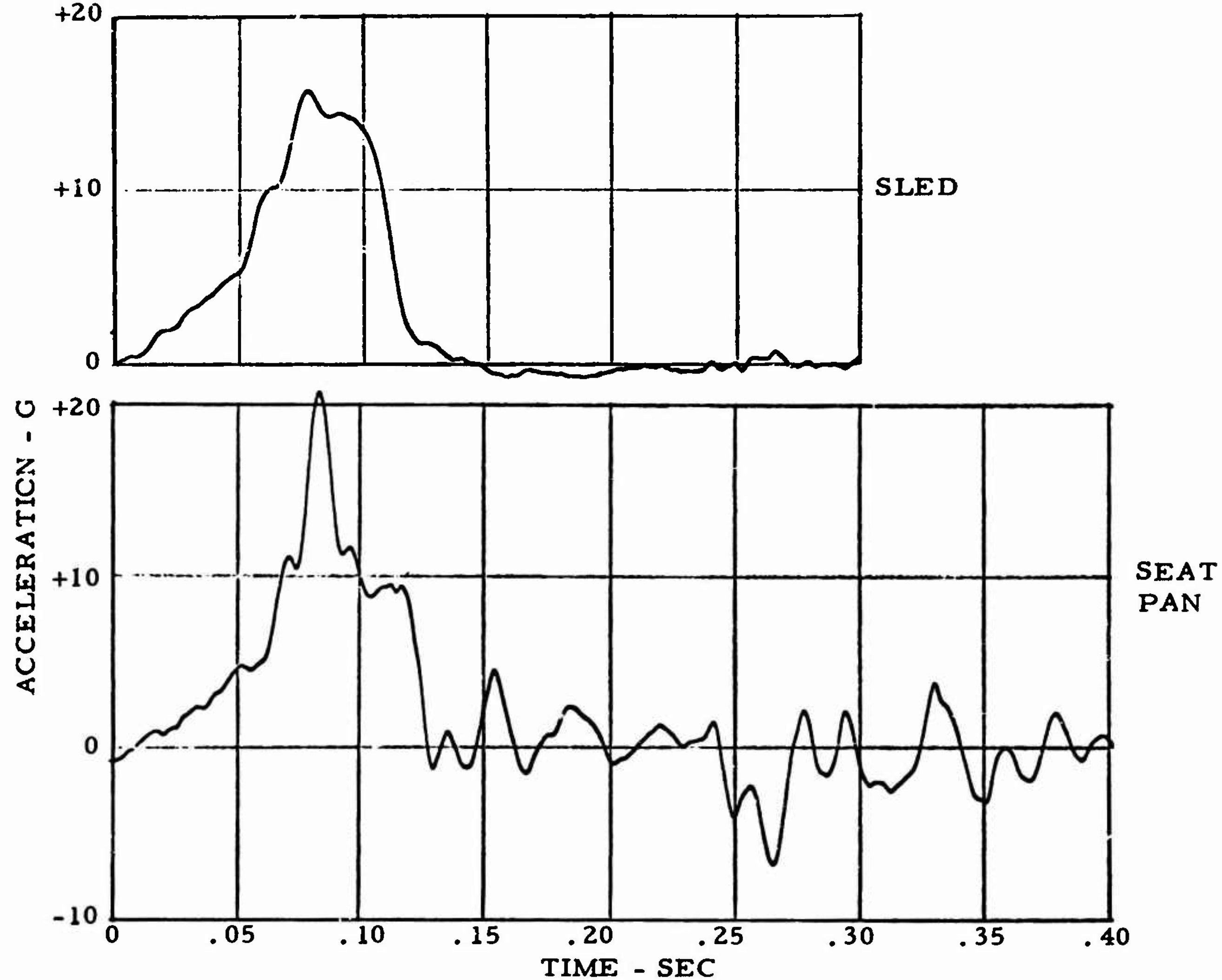



Figure 49. Test 6 Acceleration - Time Histories, Sled and Seat Pan Accelerations (Longitudinal).

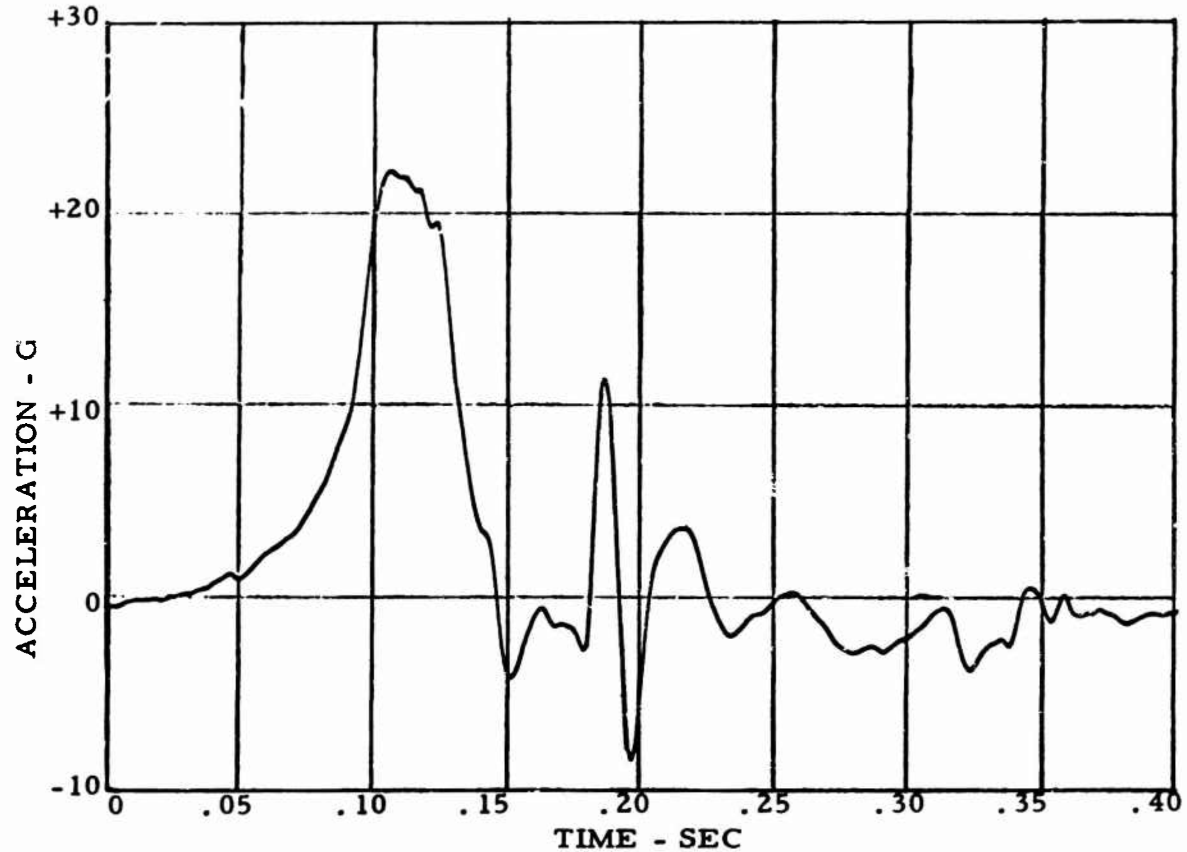



Figure 50. Test 6 Acceleration - Time History, Occupant Pelvic Acceleration (Longitudinal).

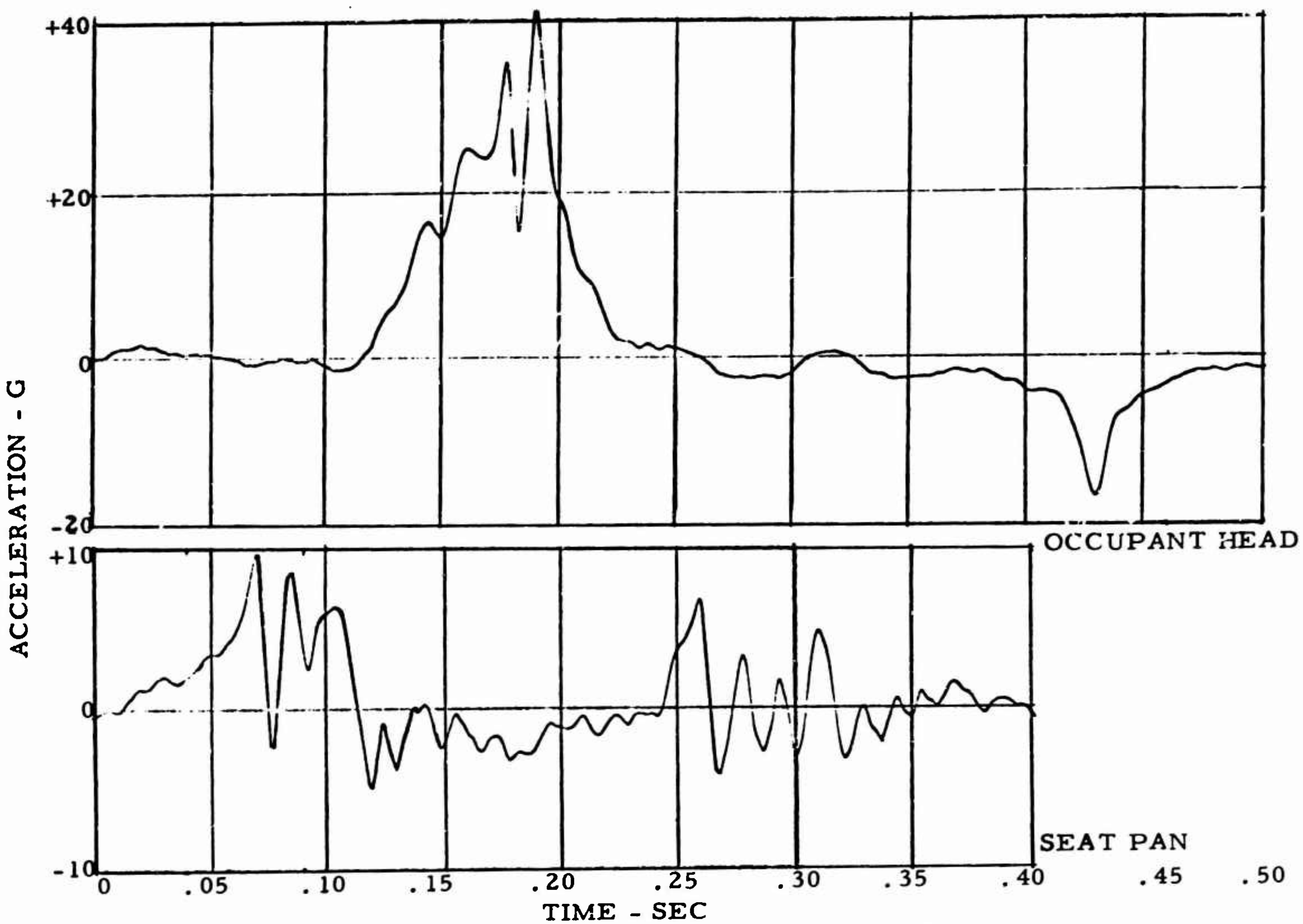



Figure 51. Test 6 Acceleration - Time Histories, Occupant Head (Longitudinal) and Seat Pan (Vertical) Accelerations.

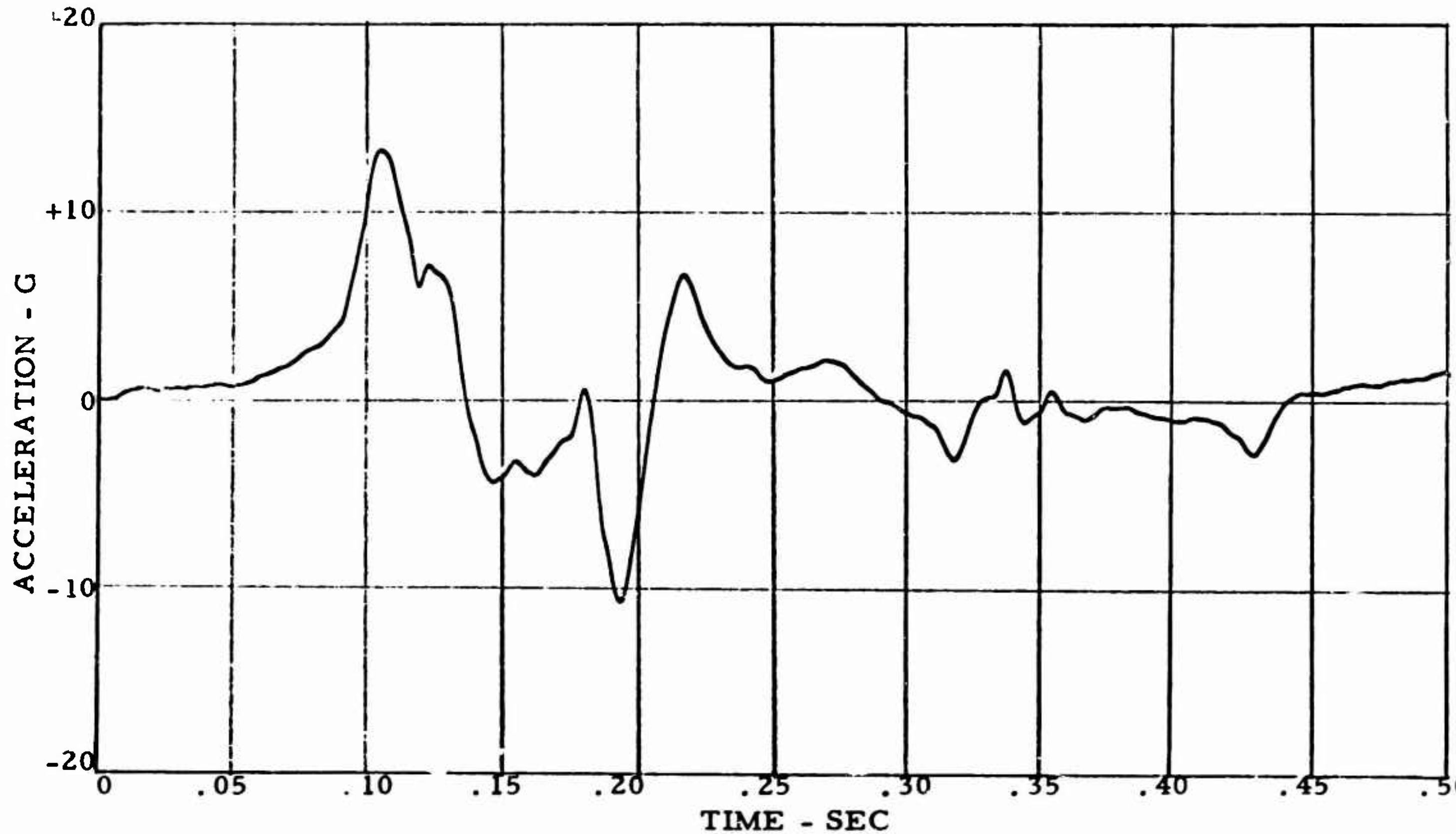



Figure 52. Test 6 Acceleration - Time History, Occupant Pelvic Acceleration (Vertical).

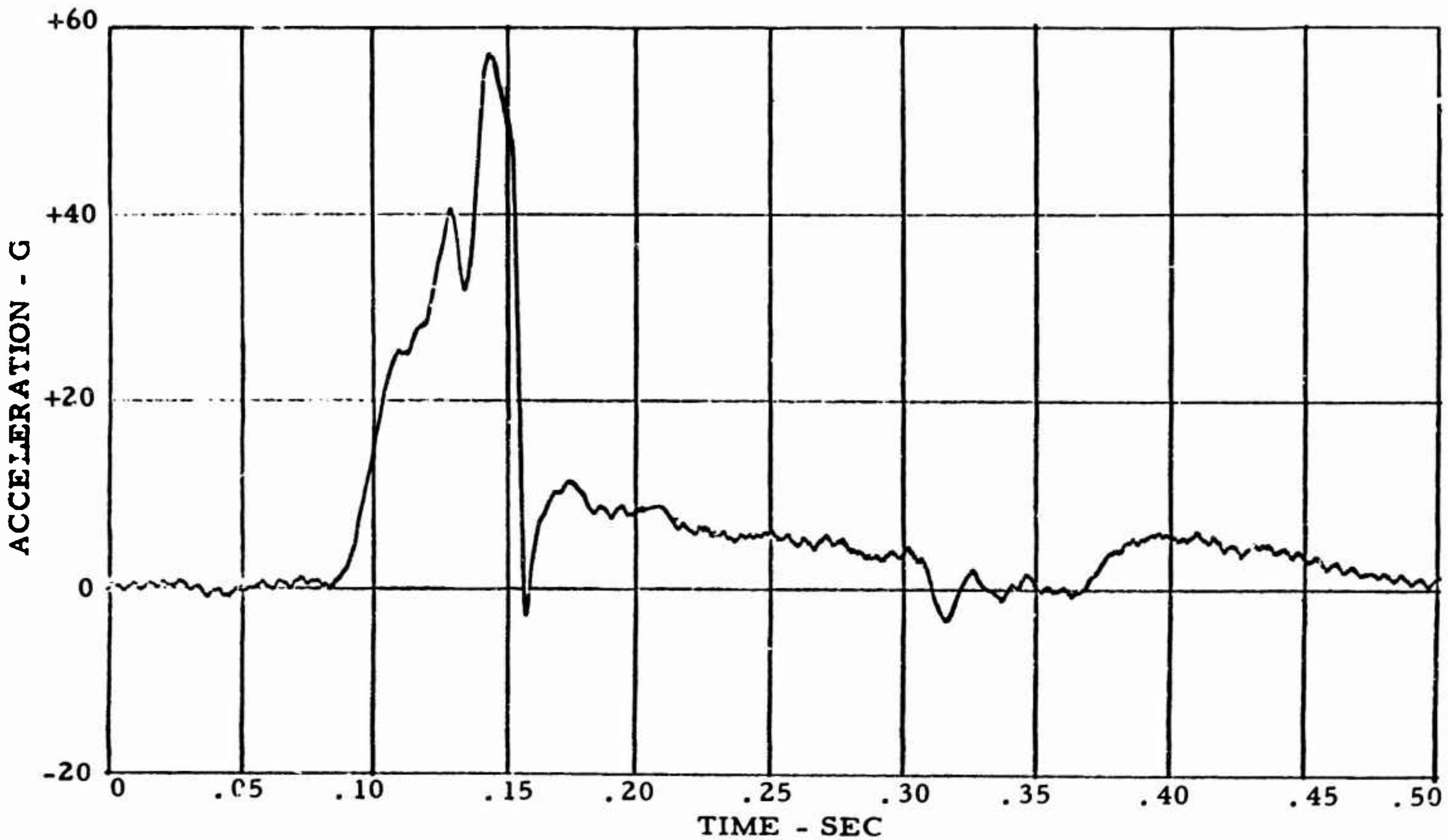



Figure 53. Test 6 Acceleration - Time History, Occupant Head Acceleration (Vertical).

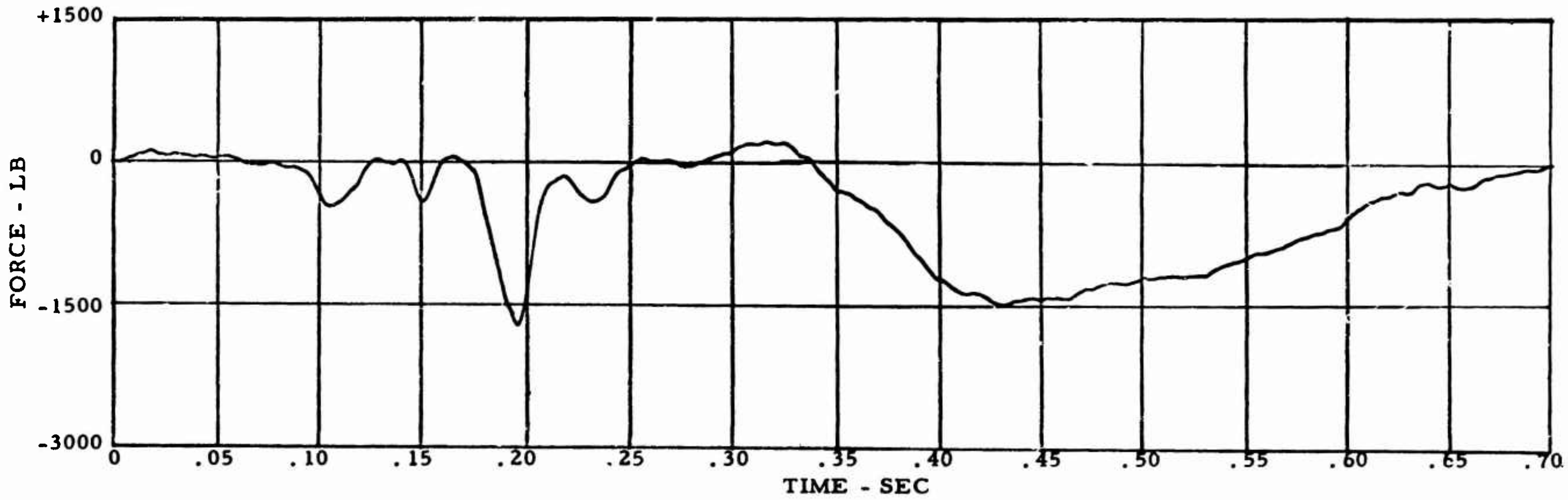



Figure 54. Test 6 Force - Time History, Occupant Vertebral Load.

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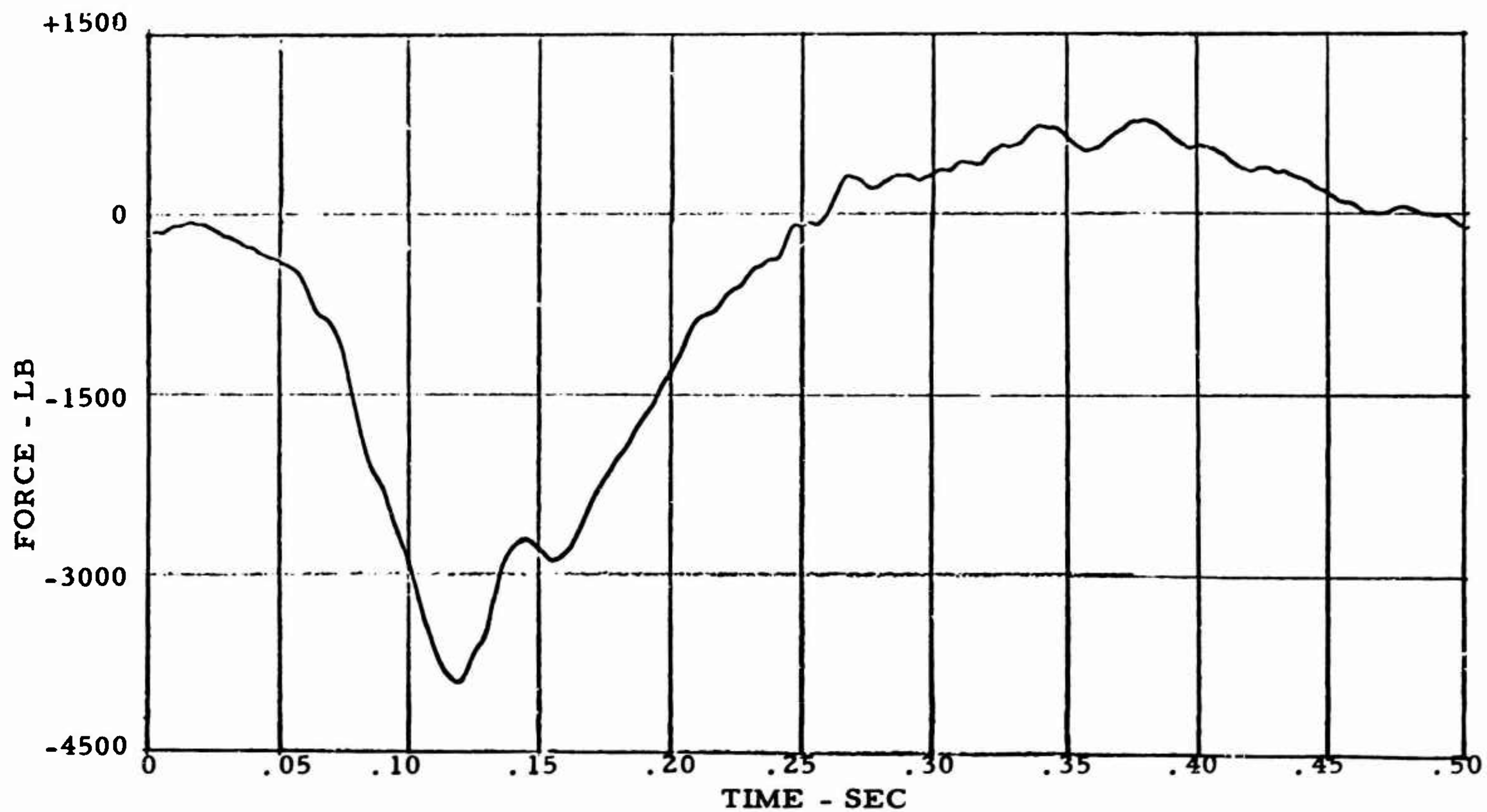


Figure 55. Test 6 Force - Time History, Right Hand Front Seat Leg Load (Vertical).

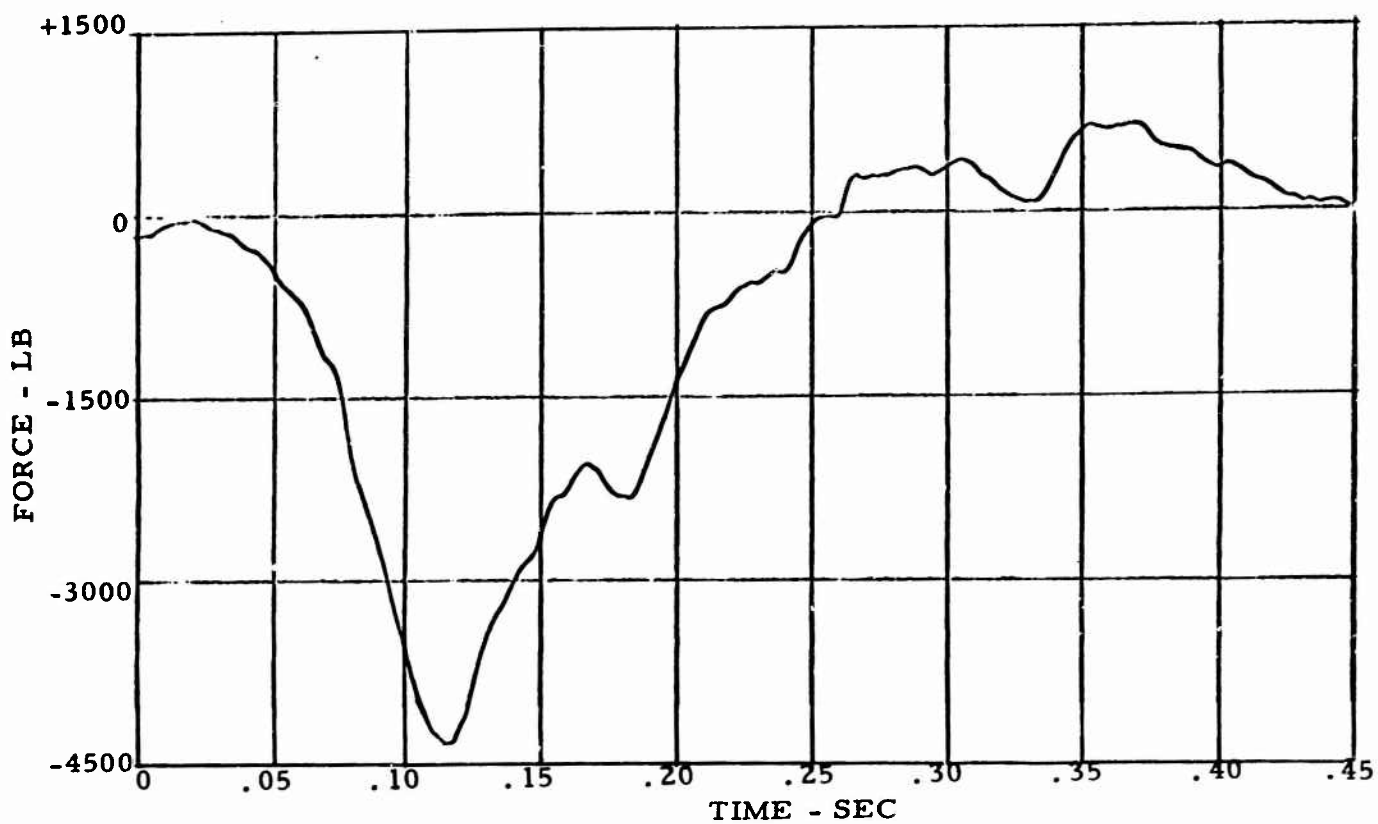


Figure 56. Test 6 Force - Time History, Left Hand Front Seat Leg Load (Vertical).

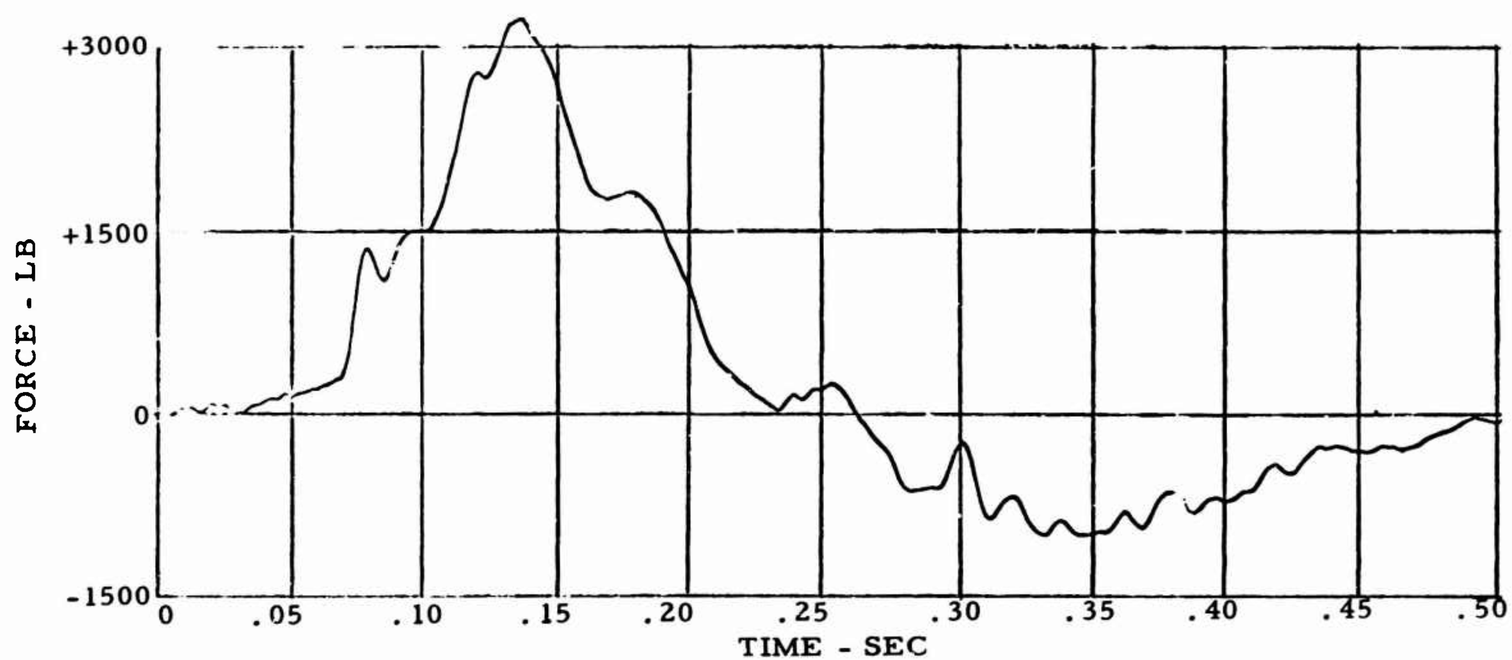


Figure 57. Test 6 Force - Time Histo , Right Hand Rear Seat Leg Load (Vertical).

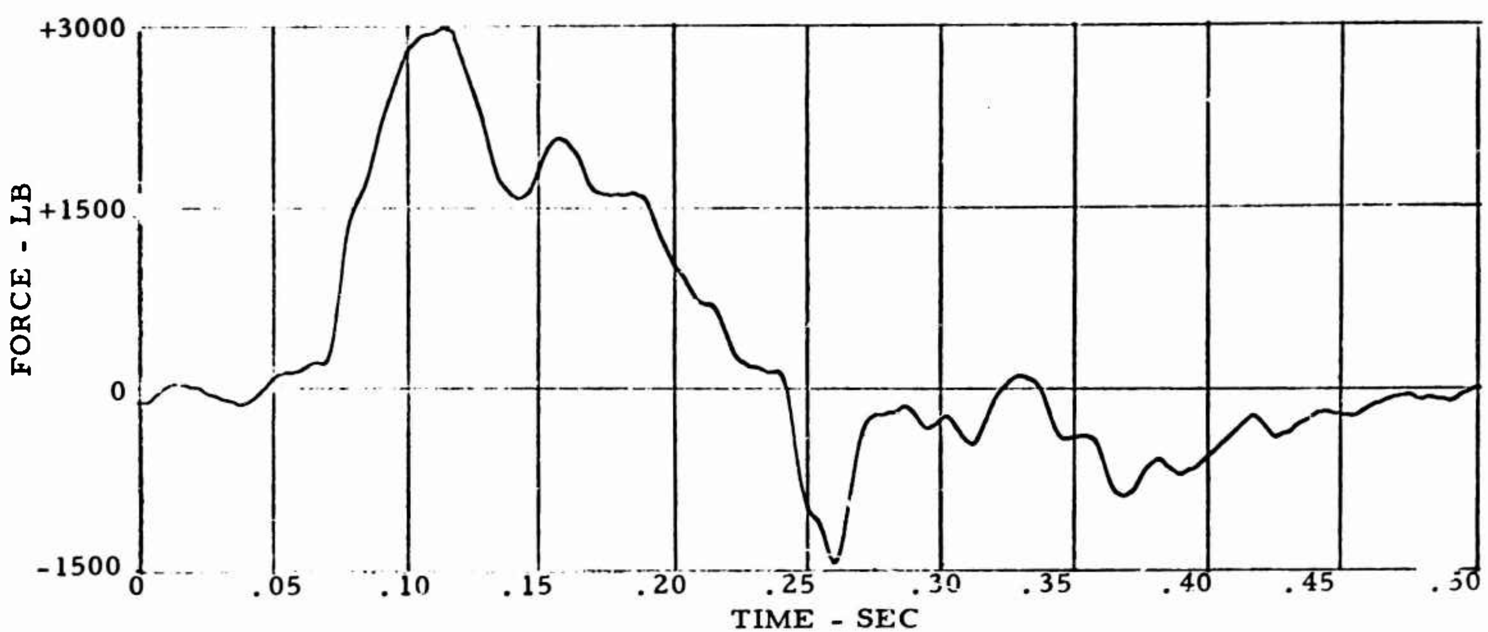


Figure 58. Test 6 Force - Time History, Left Hand Rear Seat Leg Load (Vertical).

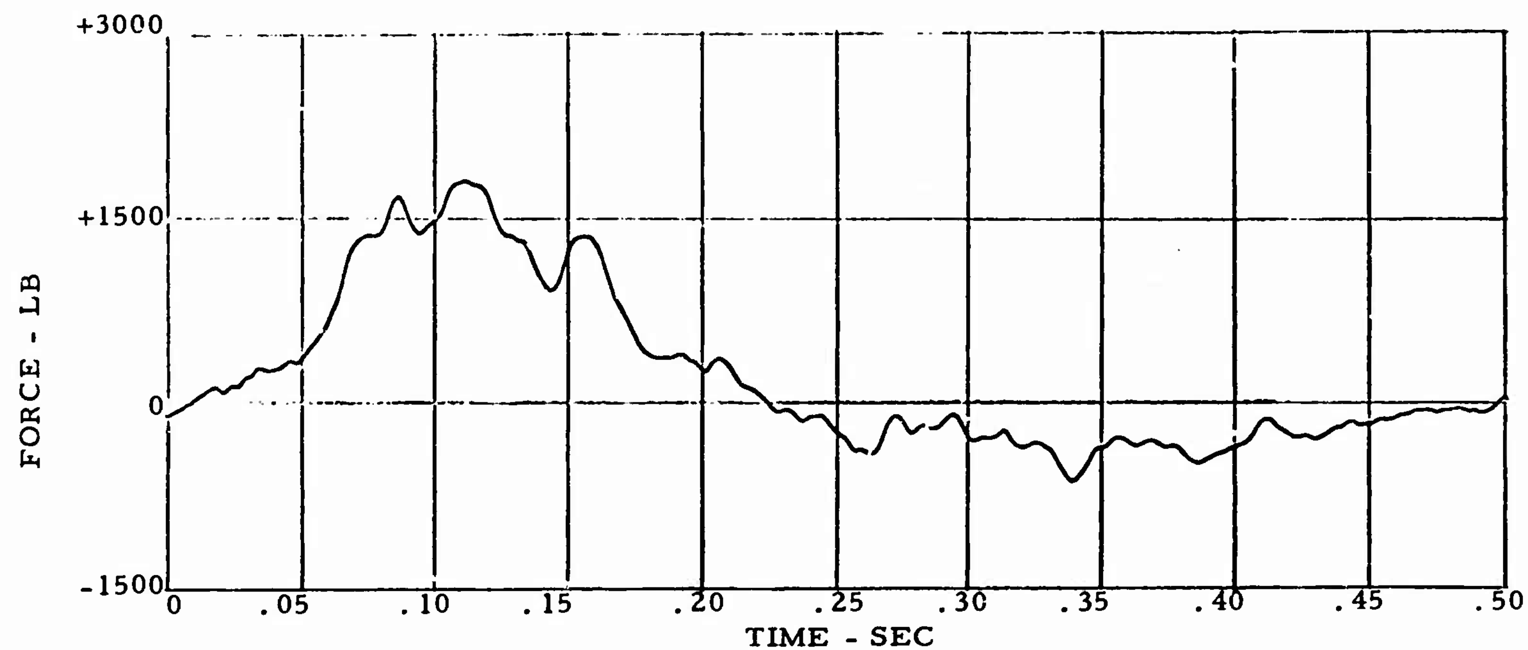


Figure 59. Test 6 Force - Time History, Right Hand Seat Load (Horizontal).

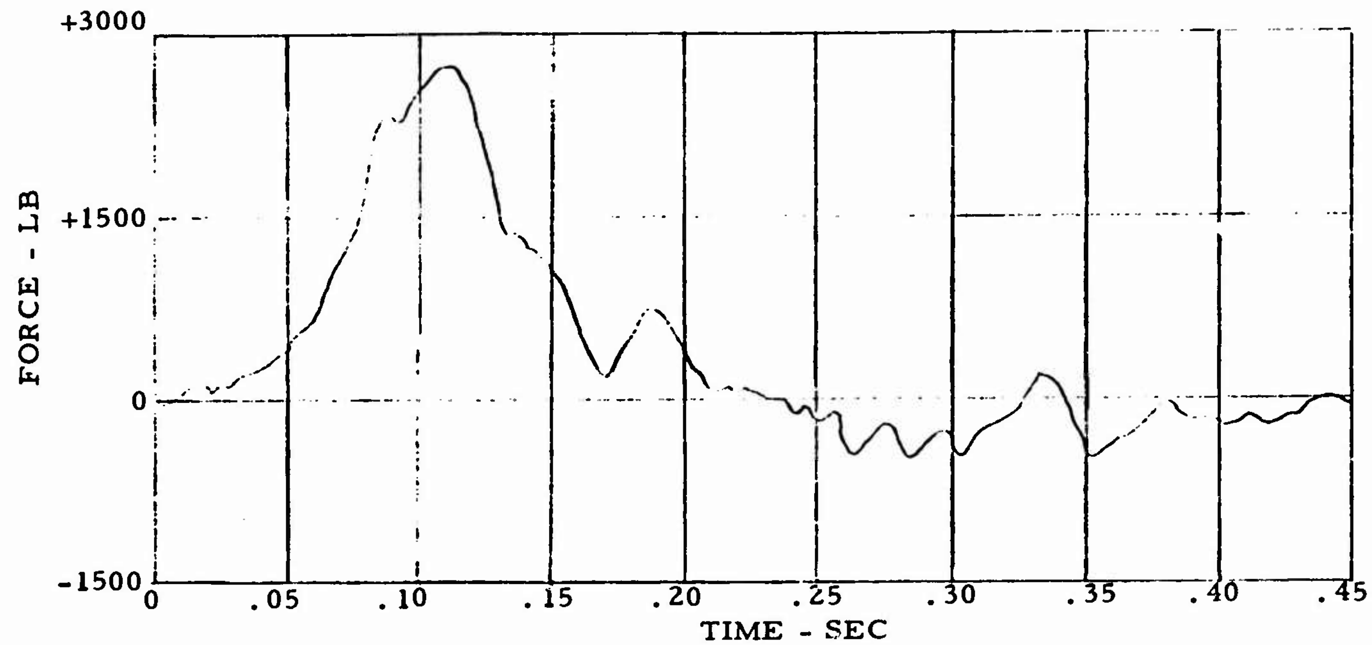


Figure 60. Test 6 Force - Time History, Left Hand Seat I oad (Horizontal).

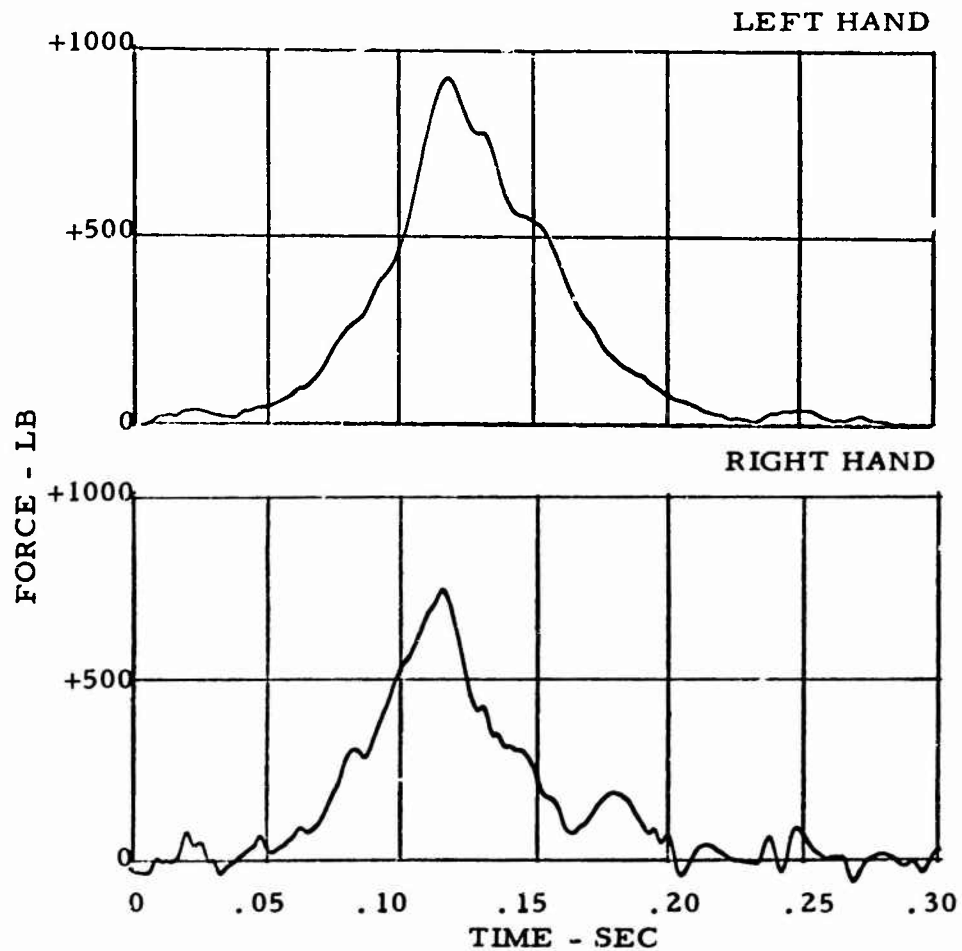


Figure 61. Test 6 Force - Time Histories, Lap Belt Loads.

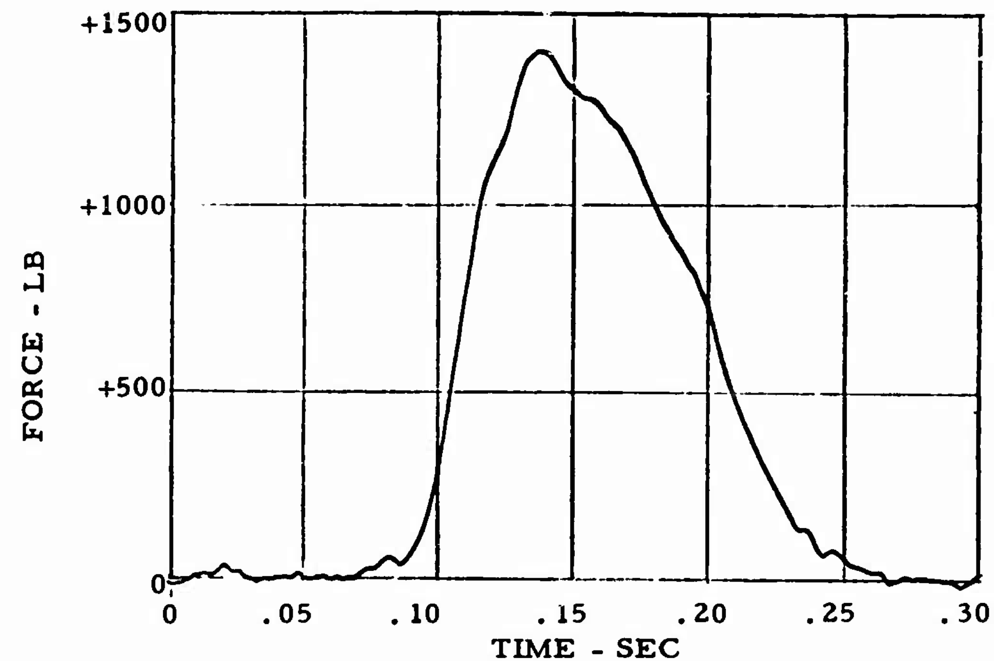


Figure 62. Test 6 Force - Time History, Shoulder Harness Load.

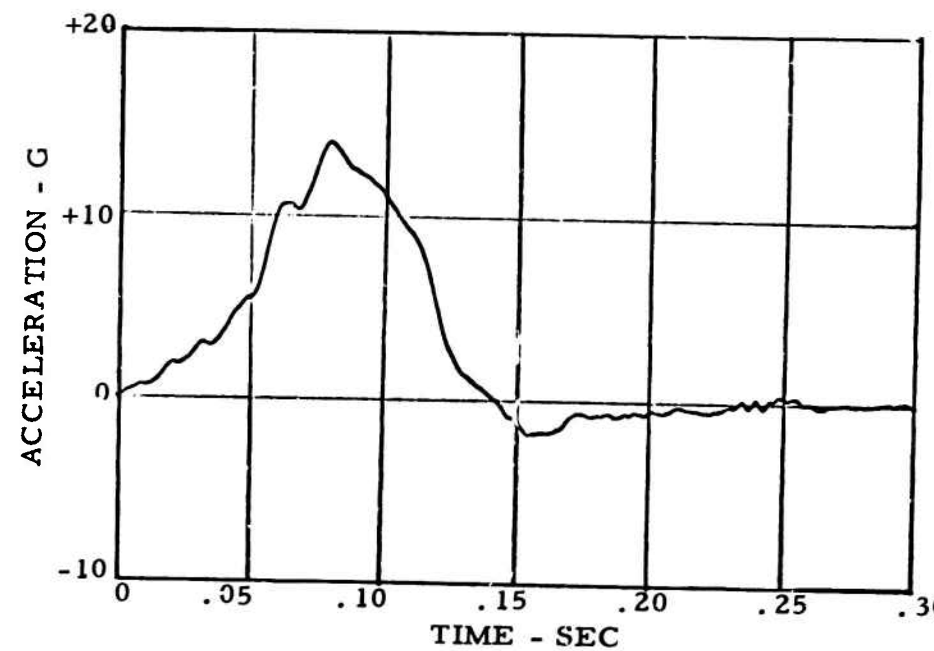


Figure 63. Test 11 Accel. ation - Time History, Sled Acceleration (Longitudinal).

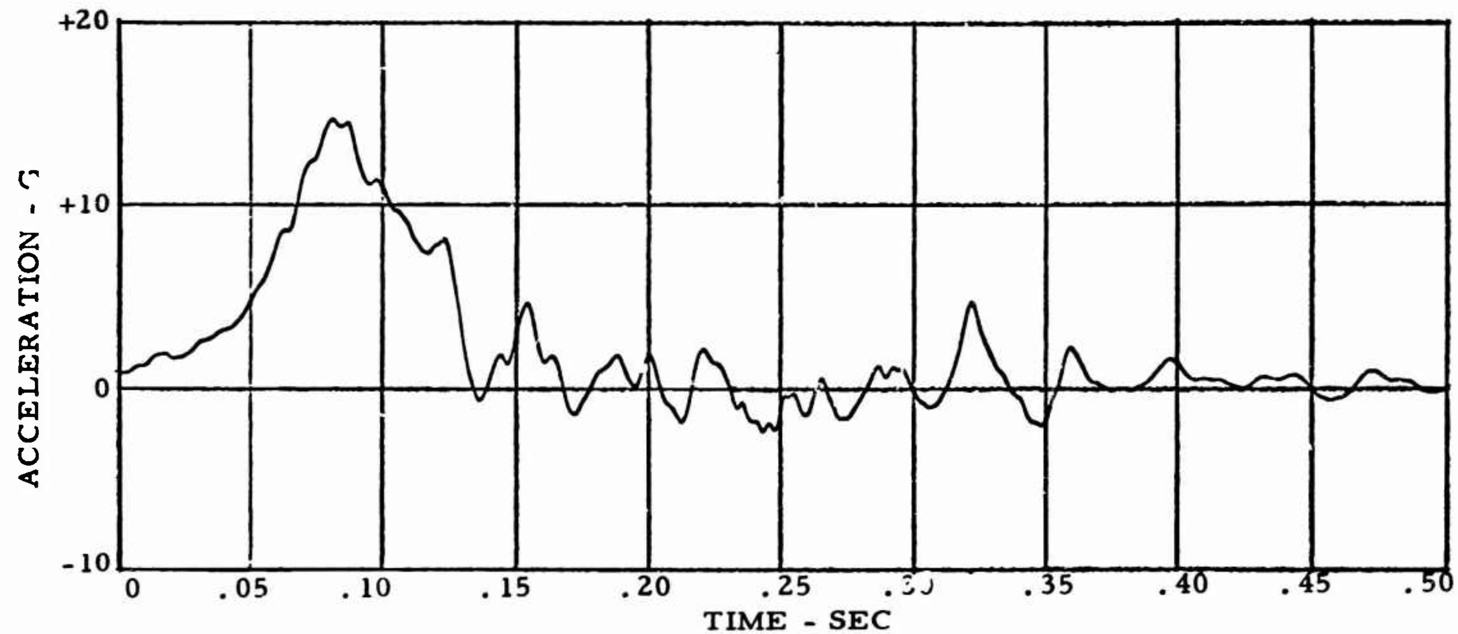


Figure 64. Test 11 Acceleration - Time History, Seat Pan Acceleration (Longitudinal).

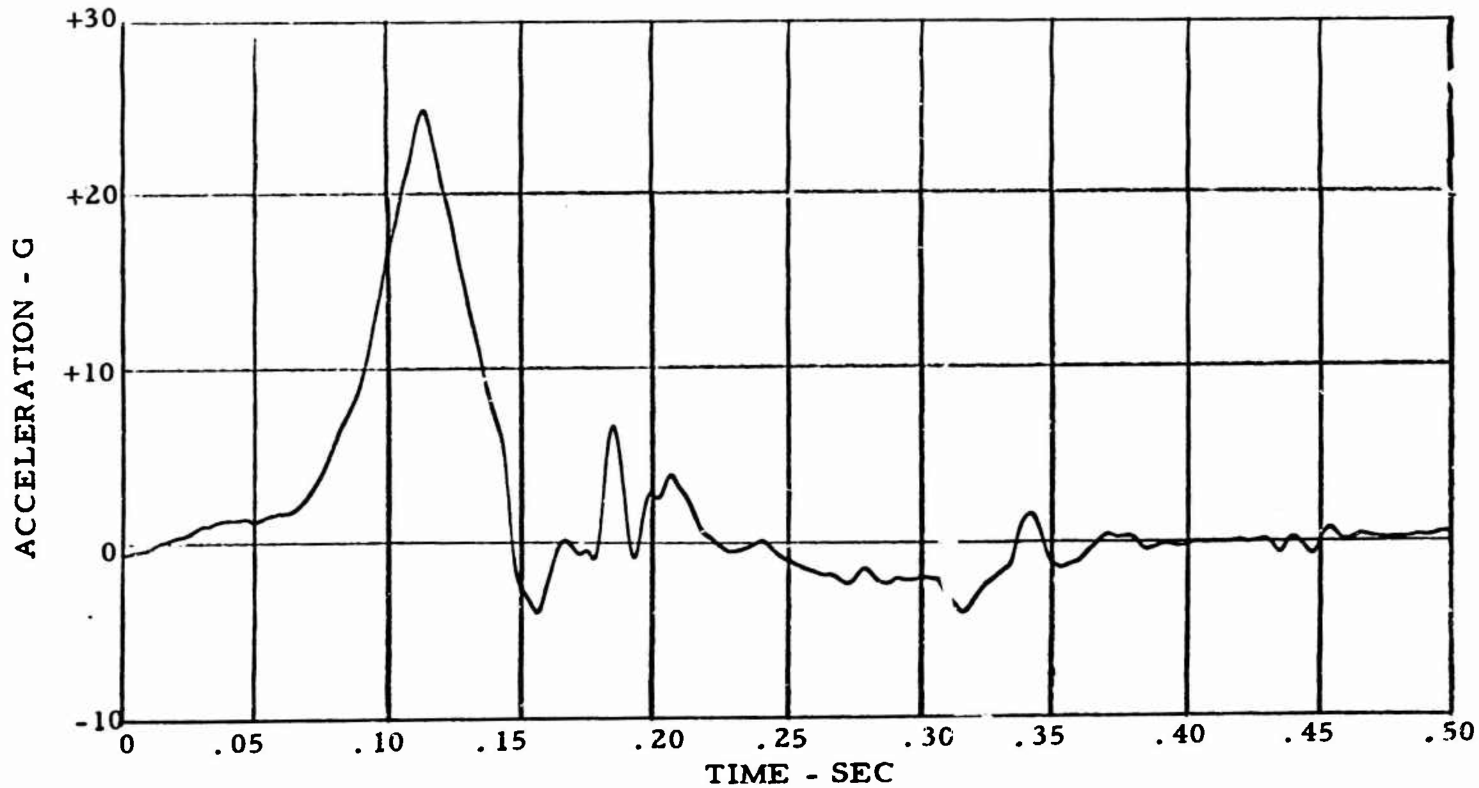


Figure 65. Test 11 Acceleration - Time History, Occupant Pelvic Acceleration (Longitudinal).

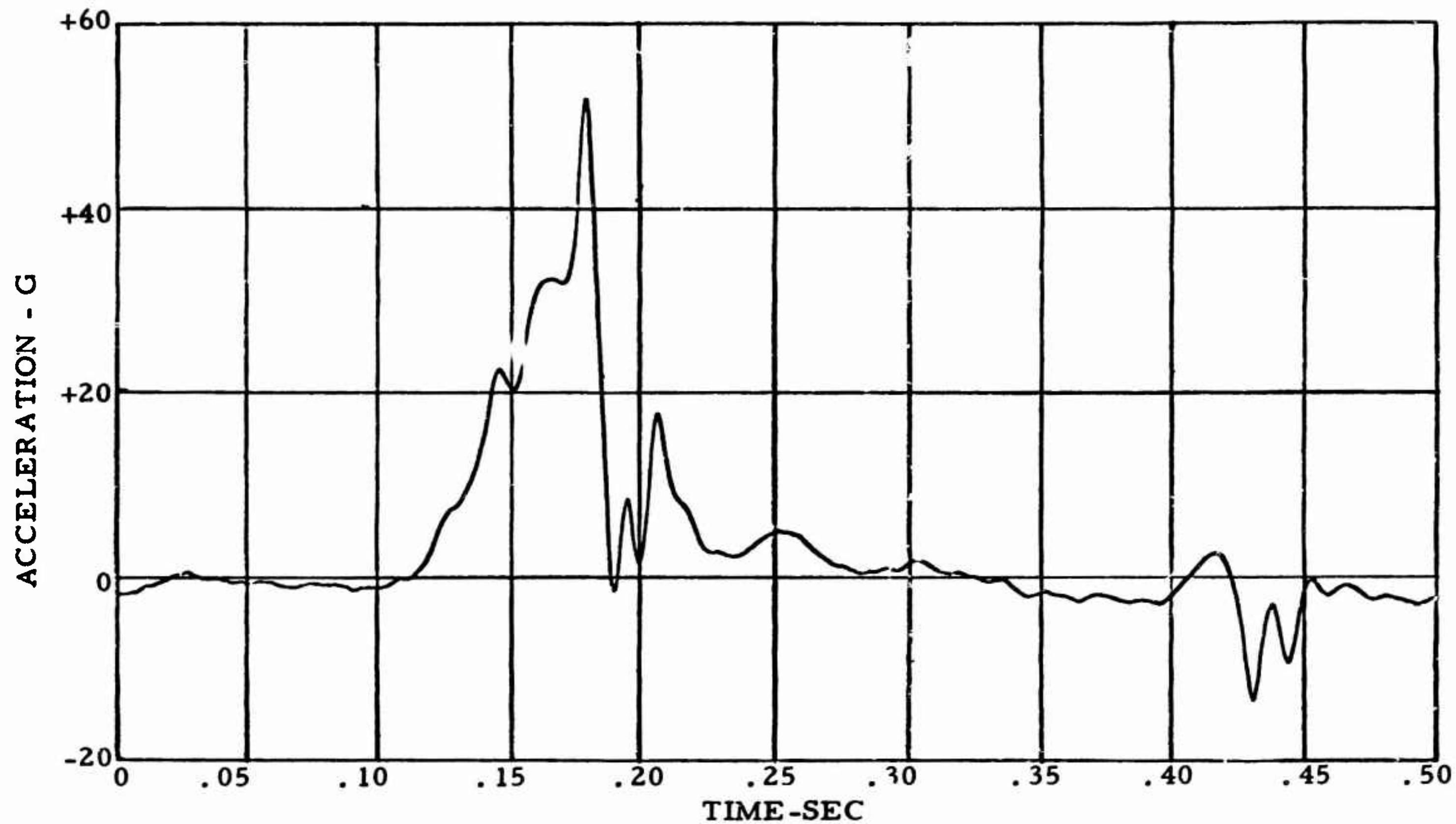


Figure 66. Test 11 Acceleration - Time History, Occupant Head Acceleration (Longitudinal).

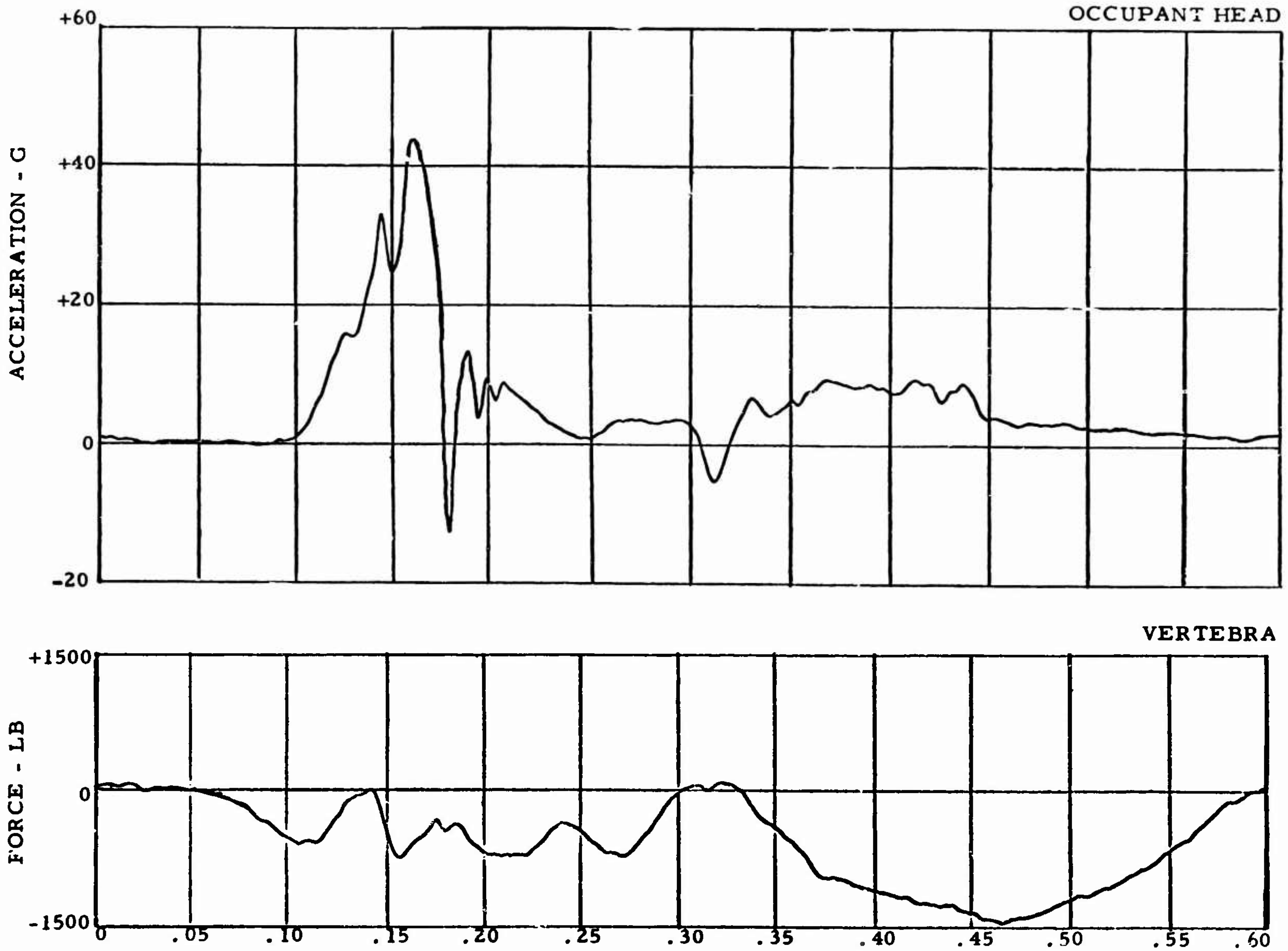


Figure 67. Test 11 Acceleration/Force - Time Histories, Occupant Head Acceleration and Vertebral Load.

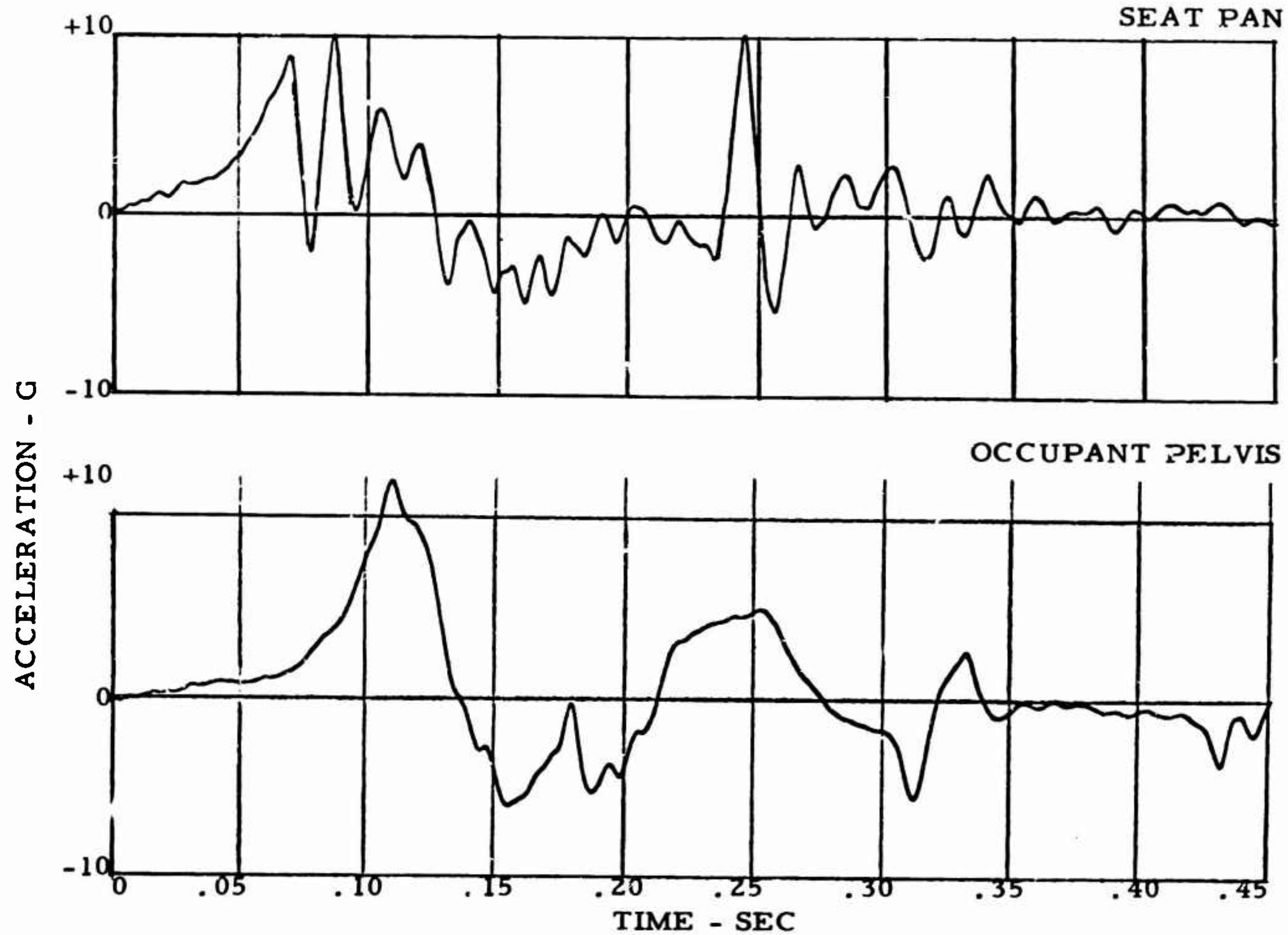


Figure 68. Test 11 Acceleration - Time Histories, Seat Pan and Occupant Pelvic Accelerations (Vertical).

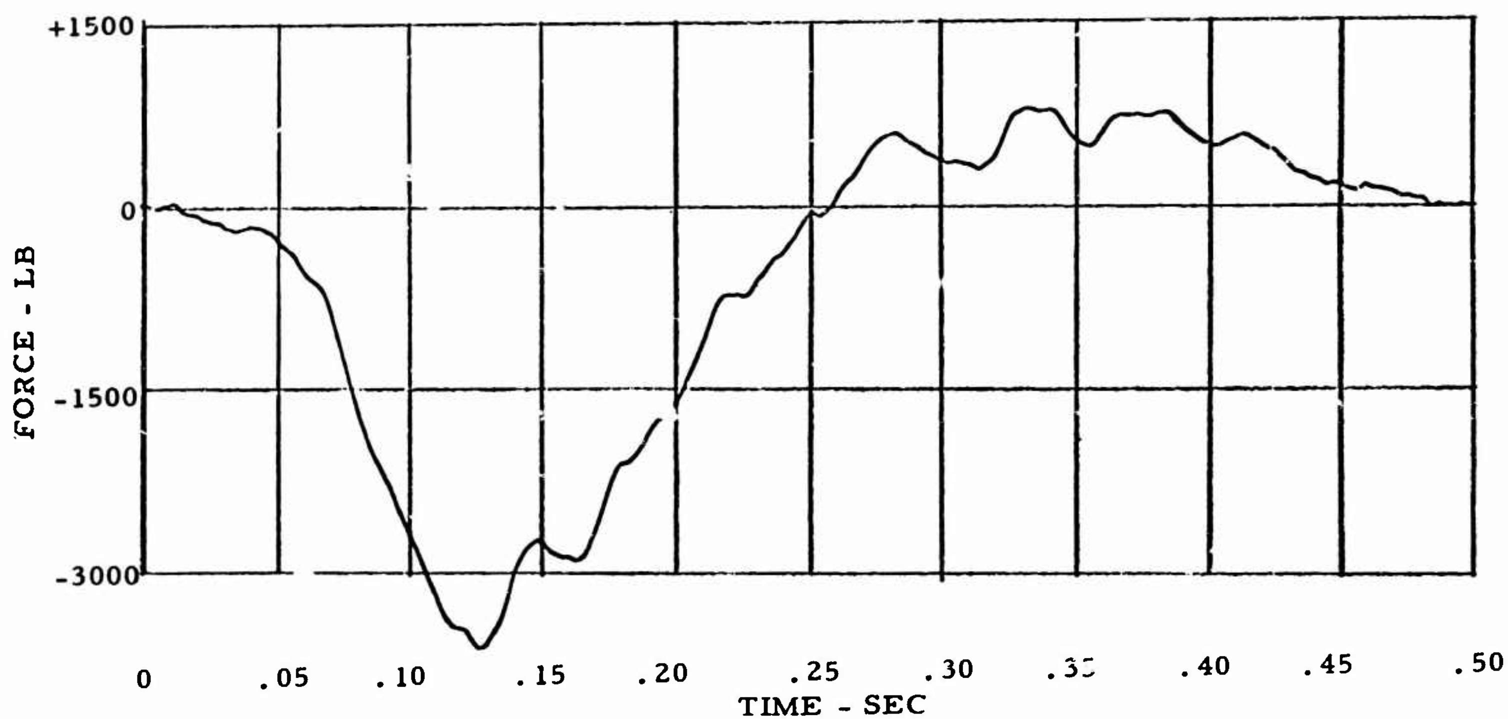


Figure 69. Test 11 Force - Time History, Right Hand Front Seat Leg Load (Vertical).

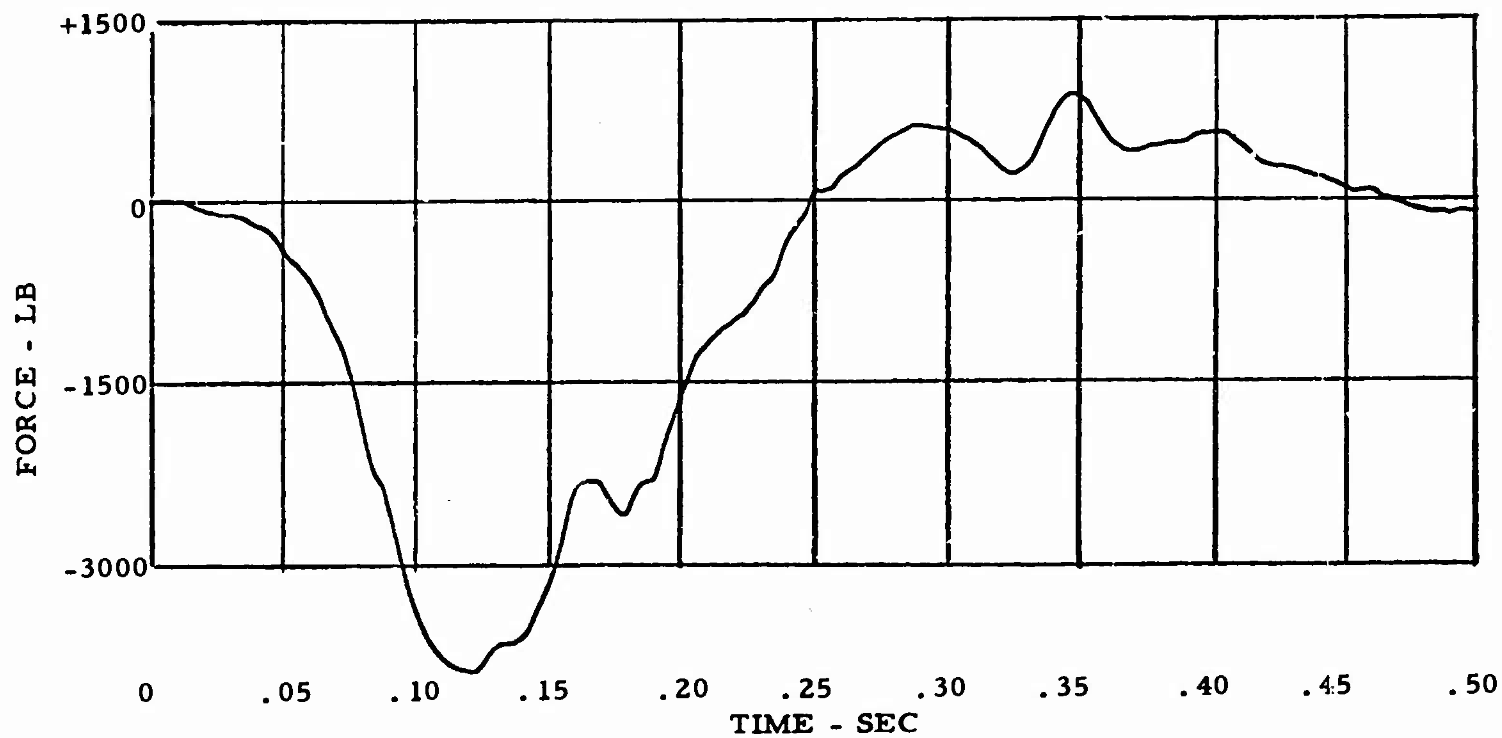


Figure 70. Test 11 Force - Time History, Left Hand Front Seat Leg Load (Vertical).

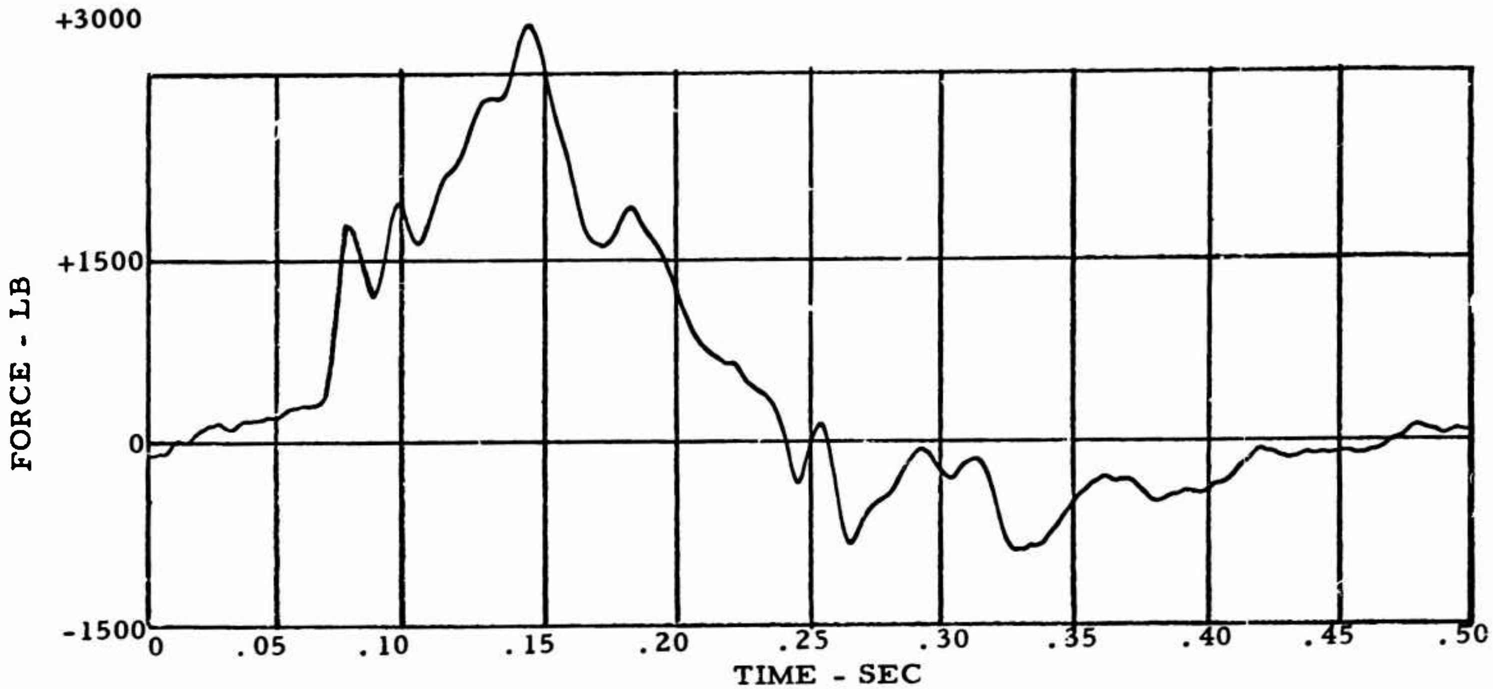


Figure 71. Test 11 Force - Time History, Right Hand Rear Seat Leg Load (Vertical).

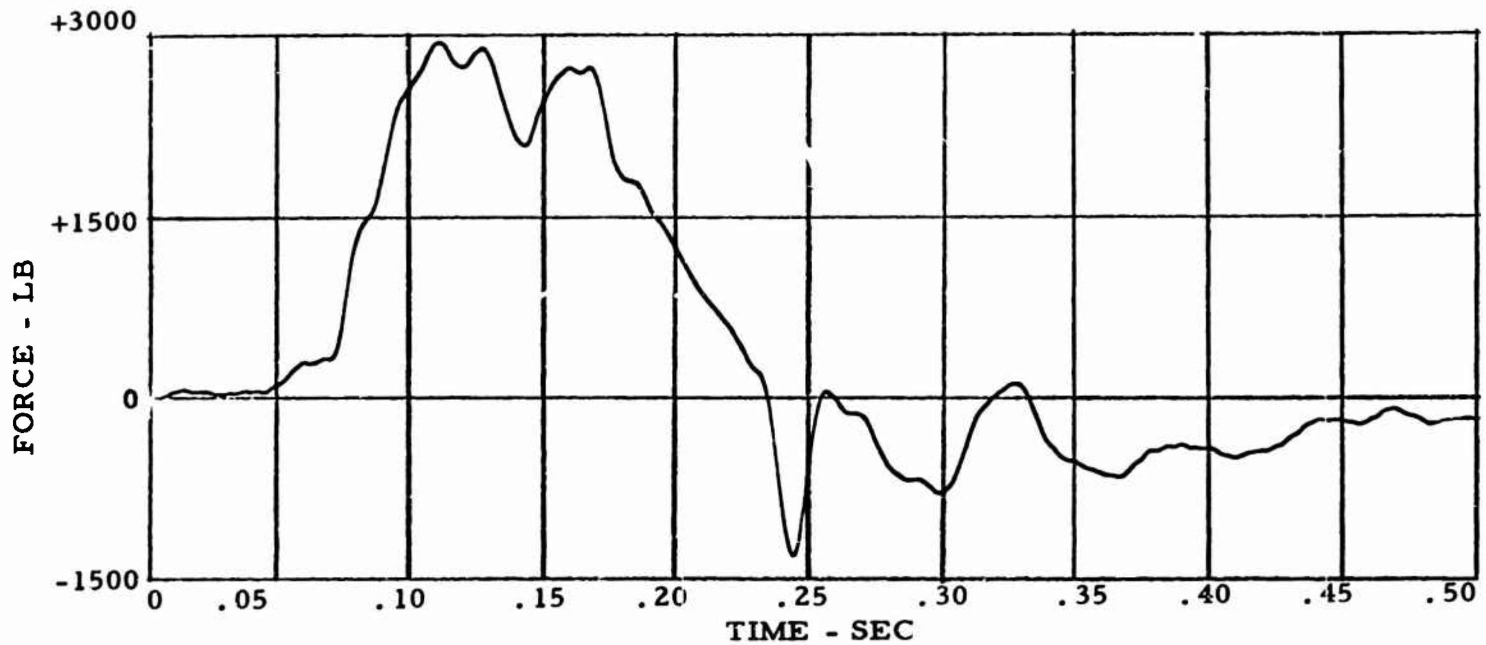


Figure 72. Test 11 Force - Time History, Left Hand Rear Seat Leg Load (Vertical).

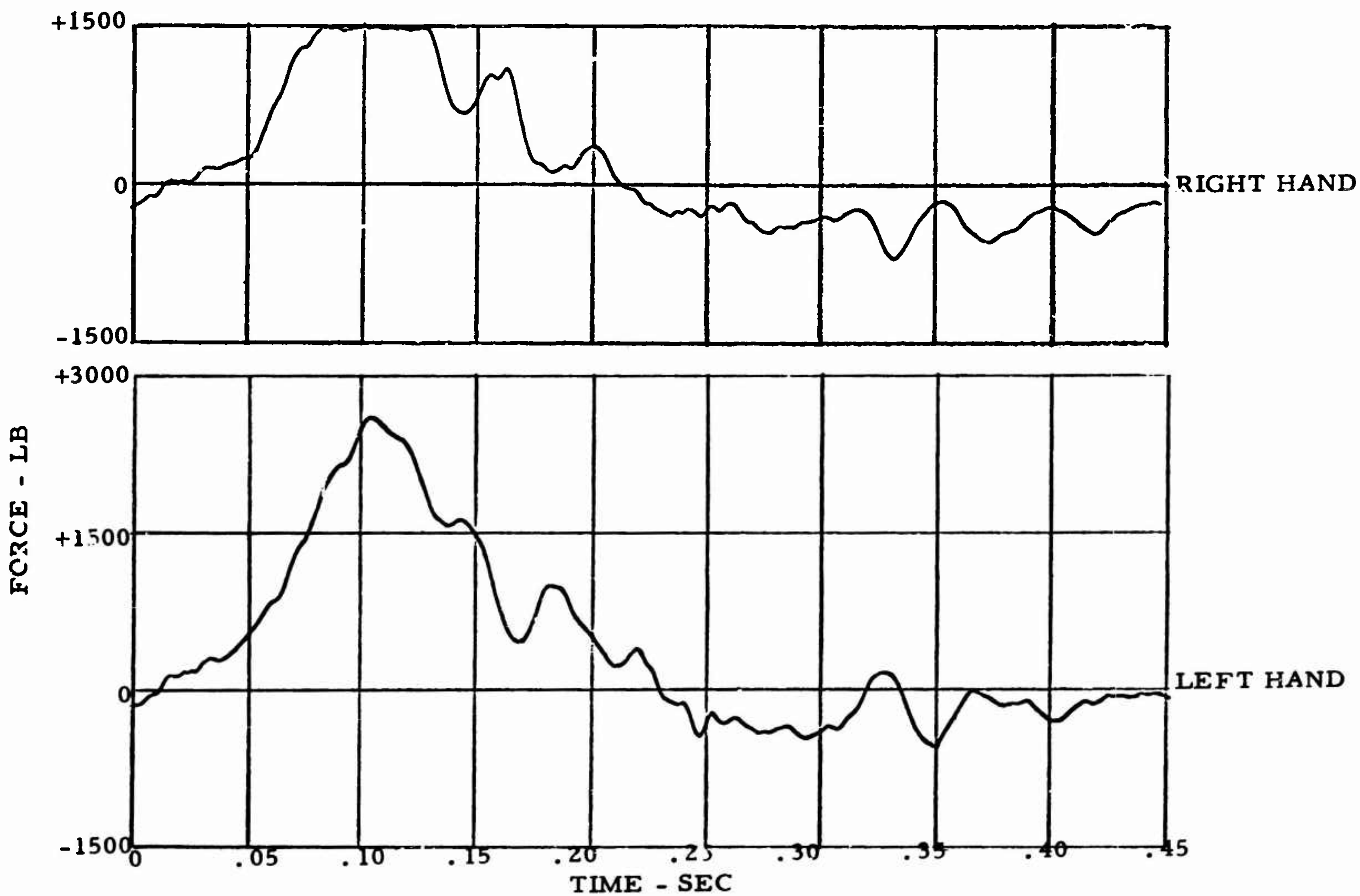


Figure 73. Test 11 Force - Time Histories, Seat Loads (Horizontal).

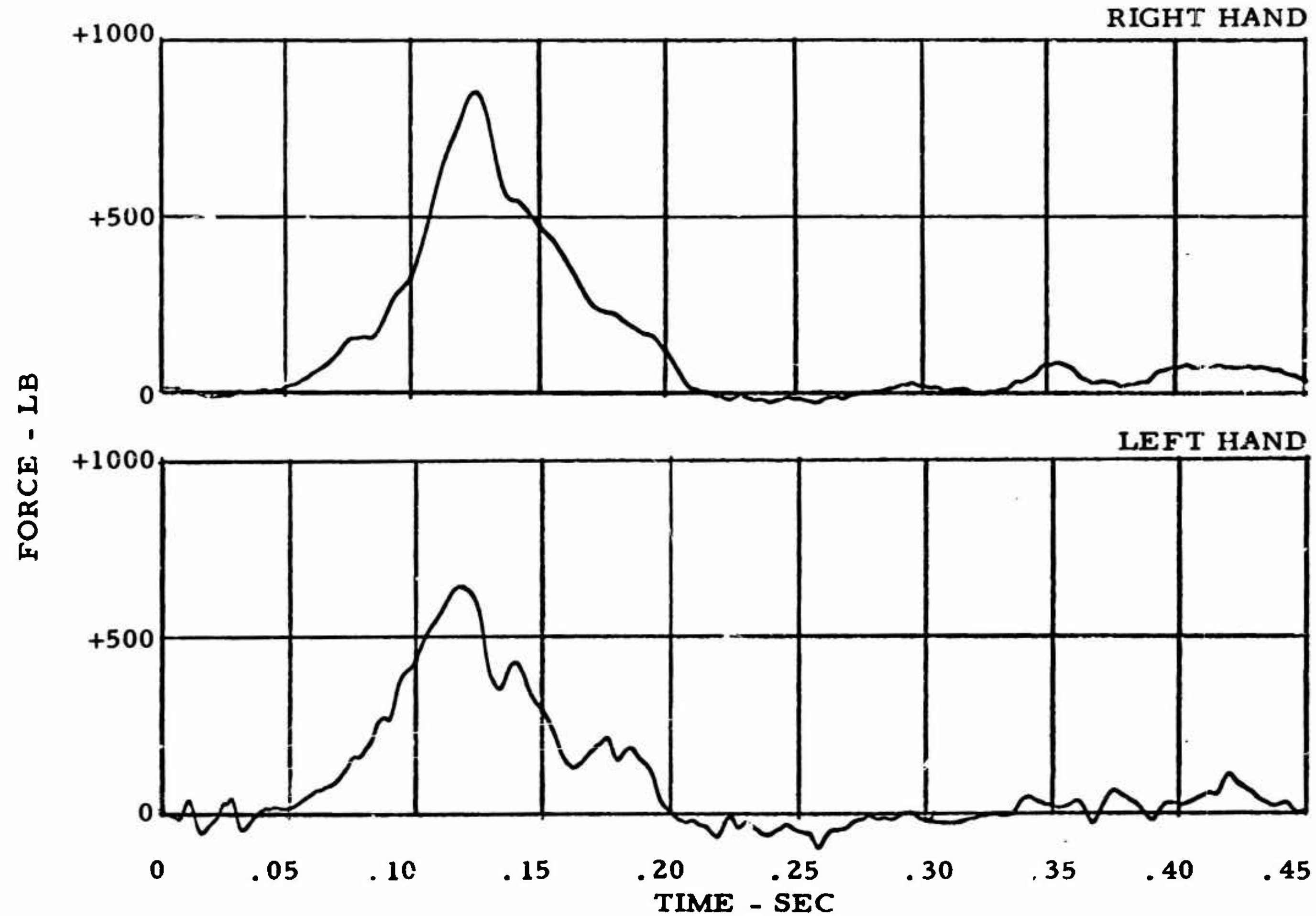


Figure 74. Test 11 Force - Time Histories, Lap Belt Loads.

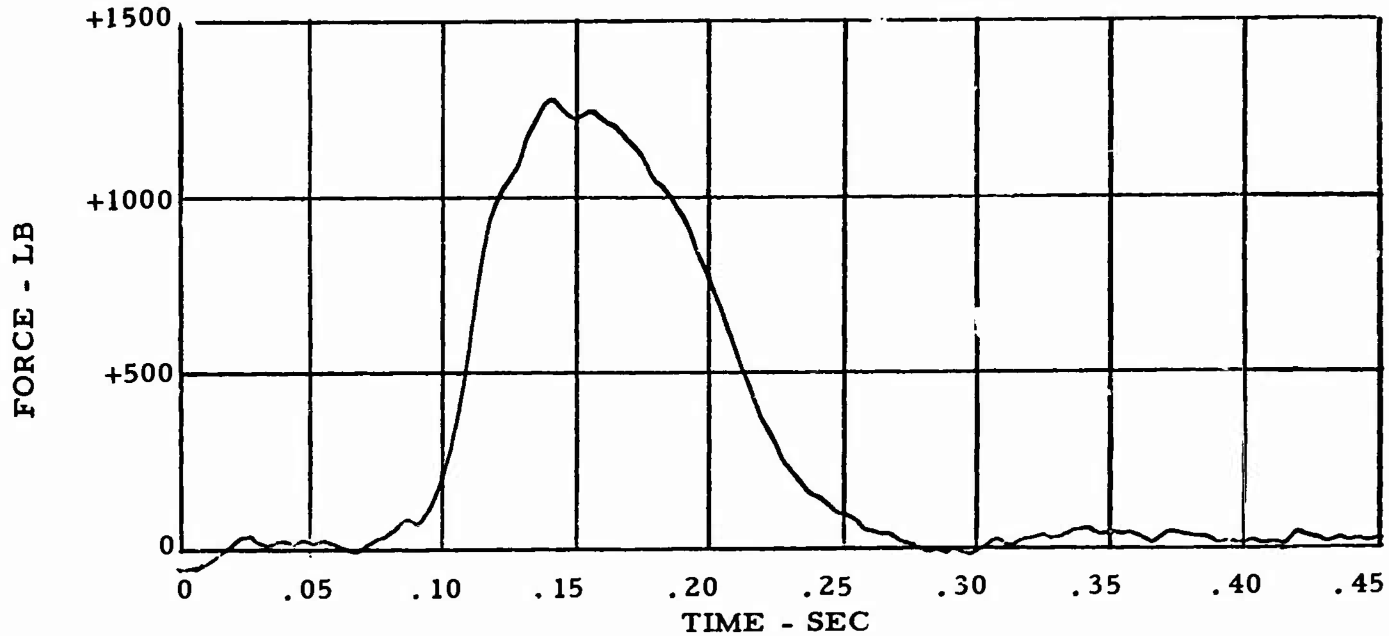


Figure 75. Test 11 Force - Time History, Shoulder Harness Load.

## APPENDIX D

## TESTS OF CURVED CHEST ARMOR PLATE

## APPENDIX D
## TESTS OF CURVED CHEST ARMOR PLATE

### General

In addition to the personnel armor discussed earlier in this report, the U. S. Army Natick Laboratories furnished one example of an experimental curved chest armor plate and requested that it be tested and evaluated.

Two tests were performed on this armor using the same test setup and impact conditions employed in the 12 previous tests.

### Description of Test Item

The experimental chest armor consisted of a ceramic-covered, fiber glass plate molded to partially encase the wearer's chest. The upper edge of this plate is also curved outward away from the wearer's face. No carrier was furnished but straps bonded to the inner surface of the plate allowed this armor to be mated with the back half of the standard armor carrier. One half of a Velcro fastener bonded to the front plate mated with the other half on the back carrier to secure the armor at the waist.

### Instrumentation

The instrumentation and cameras used in these two tests were as shown in Figure 16. No load cell was mounted on this armor. The upper inside surface of the armor was coated with black enamel just prior to each test. Transfer of the wet enamel to the dummy's face during impact served to locate the point of head/armor contact.

### Test Conditions

Impact conditions and seat orientation for these tests were as described in Appendix A. Figure 76 shows a typical test setup prior to testing.

### Test Agenda

Two tests were conducted on this armor, with the only difference being the initial location of the shoulder harness straps on the armor.

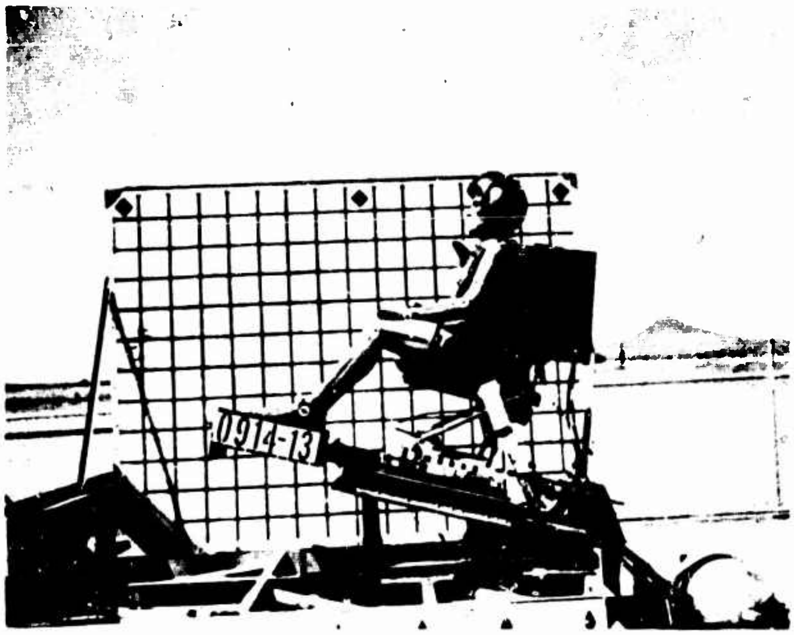


Figure 76. Typical Test Setup.

In Test 13, the straps were placed around the sides of the armor, while in Test 14, the straps were passed over the top of the armor. Figures 77 and 78 show pretest front views of Tests 13 and 14.

Discussion of Test Results

In both tests, head/armor contact occurred. In Test 13, the point of contact was on the nose and upper lip. Enamel was also transferred to the liner of the helmet. In Test 14, the point of contact was on the chin. Figures 79 and 80 show posttest front views of these two tests. Although no impact loads were measured, these impacts were more severe than those experienced in tests with the standard armor. This is evidenced by the fact that the measured longitudinal head accelerations were in excess of 100G in these tests, compared to 40-60G with the standard armor.

The increased severity of head/armor contact is potentially more dangerous from two standpoints. First, the head accelerations are approaching a dangerous level (in excess of 100G). Second, contacts at the base of the nose, as in Test 13, are potentially more injurious than the contacts of the same magnitude which occur on the forehead or chin.

This increased severity is probably due to the fact that the curved armor configuration substantially reduces the effectiveness of the

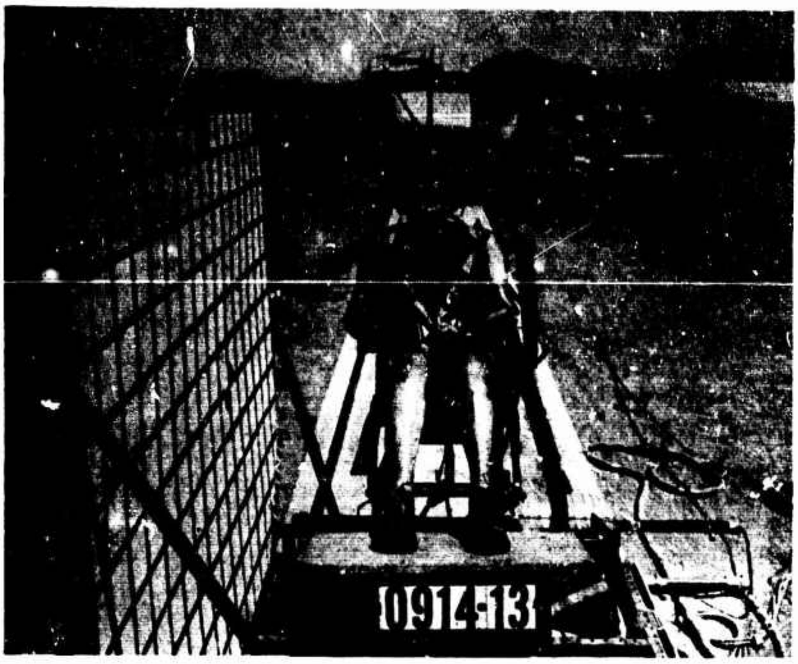


Figure 77. Pretest Front View - Test 13.

Figure 78. Pretest Front View - Test 14.


Figure 79. Posttest Front View - Test 13.

Figure 80. Posttest Front View - Test 14.

restraint system. This is especially true of the upper torso restraint since the front curve on the armor tends to hold the shoulder harness away from the body. During deceleration the upper torso and head are thus free to develop excess velocity with respect to the seat before contacting the armor.

Lower torso restraint is also compromised due to the fact that the front curve of the armor causes the shoulder harness to pull up and out on the lap belt, forcing the belt away from the body.

Conclusions

Based on the rather limited data collected during these two tests, it is concluded that:

1. Head/armor contact with the curved armor is more severe than with the standard armor under the same deceleration conditions.

2. The point of head/armor contact with the curved armor is more unpredictable and may be a function of the way in which the shoulder harness is worn.

3. The curved armor seriously compromises the effectiveness of the restraint system, especially upper torso restraint.

Recommendations

Based on the foregoing conclusions, it is recommended that the curved armor not be considered at the present time.

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13. ABSTRACT

The results of a test program conducted to determine the magnitude, duration and shape of the force-time relationship resulting from head impact on personnel armor in a crash situation are presented.

The program was divided into two major tasks. The first included modification of an armor front torso plate to carry the test instrumentation, modification of the anthropomorphic dummy to improve human simulation, and modification of the UH-1B/D armored crew seat to prevent failure. The second task involved the performance of 12 dynamic tests using two different types of aircrew personnel armor, both with and without a protective helmet.

The test results indicated that significant head/armor impact occurs most frequently in the chin area (7 times in 12 tests). Such contact produced impact pulses that were triangular in shape with peak loads ranging from 27 to 500 pounds and time duration ranging from 0.025 to 0.045 seconds. Loads on the chin of this magnitude and duration would not be expected to produce serious injury to a human being.


DD FORM 1 NOV 65 1473 REPLACES DD FORM 1473, 1 JAN 64, WHICH IS OBSOLETE FOR ARMY USE.

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13. Abstract (cont'd)

Specific modifications to the armor are recommended to further reduce the injury potential. No major seat failures occurred during the test series.

| 14. KEY WORDS | LINK A | | LINK B | | LINK C | |
|---|---|---|---|---|---|---|
| | ROLE | WT | ROLE | WT | ROLE | WT |
| Impact tests | 8 | | | | | |
| Helmets | 9 | | | | | |
| Flight crews | 4 | | | | | |
| Impact | 6 | | | | | |
| Crash tests | 8 | | | | | |
| Force | 7 | | | | | |
| Time | 7 | | | | | |
| Head (anatomy) | 6,9 | | | | | |
| Neck (anatomy) | 6 | | | | | |
| Interactions | 6 | | | | | |
| Body armor | 9 | | | | | |